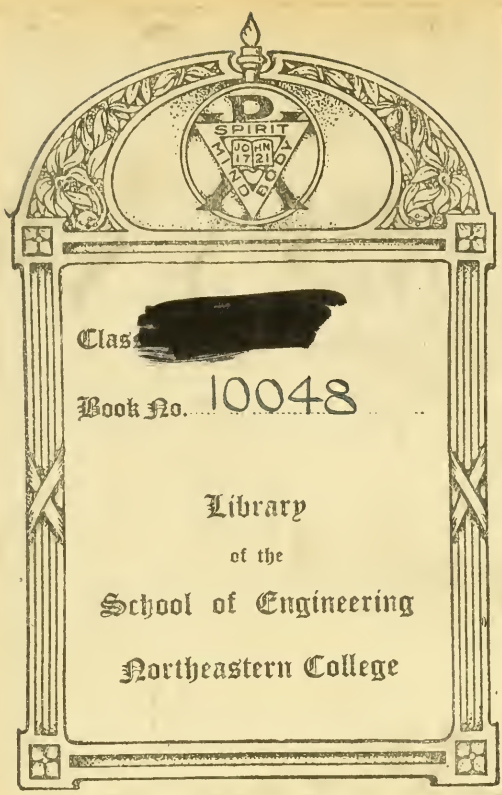

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RURAL HIGHWAY PAVEMENTS

MAINTENANCE AND RECONSTRUCTION

A Discussion of General Principles Illustrated
by Current and Recommended Practice

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PREFACE

This book is the second of a series of volumes presenting the road problem from the standpoint of the constructing engineer. It completes the text book portion of the series. This volume contains basic data ordinarily used in the design, construction, maintenance and reconstruction of rural highways.

The object of this book is to emphasize and illustrate the application of well recognized engineering principles which have been more or less befogged by non-technical propaganda. The method adopted includes development of tentative theory illustrated by typical reports covering the usual problems. Specific examples of actual practice are given throughout the text showing that if advantage is taken of the technical knowledge of engineers in connection with design and type selection, the mileage of programs can often be increased at least 10 per cent over what is actually obtained under a system of rigidly standardized and stereotyped design. Furthermore if legislatures will have foresight enough to follow engineering advice in raising funds for maintenance and renewal the total final cost of the road systems can be reduced at least 20 per cent below the usual reported costs.

The main value of this book probably lies in its definite design data, its discussions of the suitability of different pavements considering maintenance, renewal and motor vehicle operating costs, and in the selected official reports which apply the general principles of design to specific cases.

Acknowledgement is made of the courteous cooperation of highway departments, material industries and individual engineers and authors in furnishing data for this manuscript. I wish particularly to acknowledge the constructive criticism of G. G. Miller, H. G. Hotchkiss, C. M. Edwards and Herbert Michaels.

Readers are to suggest additions or corrections which will make the book more useful to highway engineers.

W. G. Harger.

Rochester. N. Y.
December, 1923.

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RURAL HIGHWAY PAVEMENTS

MAINTENANCE AND RECONSTRUCTION

CHAPTER I

GENERAL ADMINISTRATIVE CONSIDERATIONS

Introduction.—Highway design is controlled by the needs of modern motor transportation. The engineer may well gauge the success of his work by the resultant increase in safety and comfort of travel and the reduction in the final cost of motor operation both to the individual motorist and to the community at large. The final cost includes the construction, maintenance and renewal of highways as well as the direct operation cost of motor vehicles. The engineer is in a position to determine quite accurately the amount of the indirect highway charges as well as the direct vehicle operation charges and he should act as an impartial agent to produce the most service for the least final cost. This is what public officials are theoretically paid for and while in self defense we all fall from ideal standards at times and forget or ignore the interests of the community, the technical type of mind is more apt to analyze the problem with less bias than the non-technical commercial element, as the engineer has less personal incentive for the distortion of facts.

As stated in the preface the object of this book is to present the highway problem from the standpoint of the constructing engineer and to emphasize the value of well recognized engineering principles which have been more or less befogged by non-technical propaganda. The constructor's point of view has not received much publicity nor has it had much effect on general highway policy and yet he is in a peculiarly advantageous position to develop sound judgment. The most effective publicity in connection with highway programs can be credited to the material industries and the organized motor interests. The widely advertised point of view of politically appointed highway officials has left its mark and recently the research engineer has received some attention. While the constructing engineer does not know so much about theory as the scientist, or about expediency as the public officials, or about the psychology of motorists as the auto club officials or about sales methods as the material industries, he comes in daily contact with actual construction and maintenance conditions and sees the weak points in procedure and the

increase in costs due to overemphasis on either theory or expediency, or perfect travel comfort or the desire to sell a million dollars worth of materials in a year.

Effective motor transportation can only be attained by the intelligent cooperation of motorists, highway engineers and legislative bodies but while cooperation is evidently correct in theory it is difficult to achieve and most of our highway troubles are due to the tendency of each of these groups to consider only their own immediate interests tinged with a strong desire for someone else to foot the bill. The motorist often desires to shift a large share of highway upkeep cost to the non-user on the score of intangible benefit. The legislatures often consider the funds raised for construction and maintenance merely as a godsend in distributing patronage rather than as a means of giving effective service and the engineers are inclined to favor excessively expensive construction as this type meets with unthinking popular approval and is easier to design and maintain. This naturally runs the cost up and is a losing proposition in the end to all concerned.

The broad general principles of effective highway design, which cannot be safely ignored without danger of extreme waste of funds may be outlined as follows. Considering limitation of funds and the highway needs of most districts, some form of the flexible type of pavement is generally the most rational and economical solution for at least 90 per cent of the rural highways of the United States. The rigid type is probably economical on 2 to 10 per cent of the rural mileage for conditions prevailing in 1923 and caution may well be exercised not to exceed these limits unless local funds are practically unlimited. Effective maintenance is necessary if any extensive highway program is to succeed and reconstruction design should in the main retain the existing type of pavement foundation although a type of surface which eliminates the oiling nuisance may well be adopted on heavy traffic roads. If some of the comments throughout the text seem a little caustic, in dealing with flagrant violations of these principles, it should be borne in mind that destructive criticism is not intended but in order to show the desirability of improvement, caustic comment may be necessary. There is so much humor in connection with the paving problem that it is impossible to write a book on this subject which at times does not depart somewhat from the conventional style of technical writing but an effort has been made to emphasize the good points of existing procedure as well as point out its shortcomings.

This book is not intended as a definite guide for the older engineers who have developed judgment. It is intended as a practical guide for the younger men and to serve this purpose it must of necessity deal largely with technical details. It is desirable however for the younger men to bear in mind that while a strict technical analysis is a good starting point

for judgment it is often necessary to modify an ideal technical solution for various reasons, such as limitations in funds, etc., in order to accomplish anything at all. That is, an engineering analysis furnishes a desirable mark to shoot at even if it cannot be carried out exactly as planned and it is encouraging to note that in the last few years legislative and construction practice has made some progress towards a desirable engineering goal. This chapter gives a short statement of the elements of the administrative problem as it affects highway design. The data is intended for the use of the younger men not entirely familiar with the problem as a whole and is not likely to be of much interest to the more experienced engineers.

Scope of Programs.—Complete highway programs include three well-defined branches coordinated by centralized administration.

1. The gradual improvement of the road system by means of the construction of modern pavements and bridges suitable for the traffic each road must carry.
2. The maintenance and renewal of such high grade improvements.
3. The immediate temporary improvement of portions of the system not yet reached by the modern construction program and the reasonable care of detours.

These factors require separate funds raised from the proper sources. The relative expenditure for these items will vary in each locality depending on its financial strength, traffic requirements, and the extent to which its road system has already been improved. The problem is well worth careful attention as the effectiveness of the program and its power to retain popular support depend largely on a well balanced treatment of these three phases of the work.

As a rule, communities do not consider highway improvements strictly as a business investment. They look at this matter a good deal as an individual considers the purchase of a home or an automobile. If he can afford a $50,000 house or a high grade car, he is inclined to get it as a personal luxury but the great majority have to curtail their desires to fit the limitations of their pocket books and gauge their purchase by the scale of utility. This same analogy applies to the purchase of highways. The fact that they are public improvements often obscures such limitations but the highway executive must bear it continually in mind if he expects to provide reasonable service with the funds at his disposal.

Any rational solution depends on the service value of different kinds of improved road systems, their construction and maintenance cost, and what the community can afford to buy. *Considered in terms of convenience, pleasure, safety and general usefulness, road improvements are worth more than the community can possibly spend. If road expenditures are considered as a business investment immediately returnable in the saving of travel cost, the greatest proportional return is obtained by restricting construction to the standard of general utility,* by which is meant a standard of

excellence that meets necessary traffic requirements but eliminates the fancy extras. Even the richer states cannot raise enough money to complete general utility systems as rapidly as they would like and it is important to consider how to get the most benefit for available means.

The construction of modern pavements has received the bulk of attention in most states during the past fifteen years (1905 to 1920) generally to the exclusion of reasonably well-developed maintenance and temporary service departments. A number of states in which the modern high grade systems have been in use for considerable time have developed fairly efficient maintenance although in many cases the basis of financing

FIG. 2.—Efficient maintenance of existing road to give moderately good immediate service. This gravel road in Clark County, Wisconsin is on the State System and is being kept in serviceable shape for about $300 per mile per year until it can be reconstructed to a higher standard. The use of dust preventatives raises the cost to about $600 per mile year.

is not entirely satisfactory. Some states have given considerable attention to immediate temporary service programs and care of traffic on detours but it is the exception rather than the rule and this lack of appreciation of a traffic demand may easily cause serious loss of popular support of centralized state and national control of highway expenditures.

State and Federal control is a distinct advance over the old system of local control. The standards of finance, design and construction have been improved and a more uniform and coordinated system attained. It is to be hoped that the quite prevalent minor faults of centralized control, involving unnecessarily expensive construction of secondary roads and the disregard of quick temporary service, will be corrected under the stress of popular demand. Very few highway engineers are entirely satisfied with either the legislation, financing or general administrative policy of today (1922). The problem is, however, reaching the stage where the sums involved demand a fairly logical and reasonably efficient policy in order to retain continued support and it seems well worth

while to keep in mind the fundamental requirements which are necessary to give the community a satisfactory return on its investment.

General Policy.—While there is considerable variation in local application, ordinary general policy usually falls under one of the following classifications: The "Small Mileage Boulevard Policy," the "Large Mileage Cheap Pavement Policy" and the "General Utility Policy."

FIG. 3.—Construction detour in poor condition. Very expensive and annoying to traffic.

Boulevard Policy.—This policy advocates the extensive use of high first cost, low maintenance charge pavements even for roads carrying as low as 300 vehicles per day. It ignores immediate temporary improvement of existing roads. Its slogan is "Build the Maintenance into the Road." It derives its strength from the fact that the highway maintenance problem has not been very well handled in many cases, with the inference that highway maintenance cannot be well handled even if interest is aroused in the matter. This policy offers considerable freedom from the annoying problem of maintenance for the first few years; it insures extreme refinements of pleasure and convenience for travel on the roads that are actually built; it tends to keep motor taxation at a lower figure for the first few years; it appeals to the unthinking demand for spectacular boulevards but makes it impossible to provide fairly good traffic service over a large mileage of highways within a reasonably short time. That is, if quick general traffic service to all parts of the community is considered important, this policy cannot possibly succeed for districts other than rich metropolitan areas.

Cheap Pavement Policy.—The second policy (Cheap Pavement) advocates the immediate construction of a large mileage of cheaper type pavements even on heavy traffic roads. The idea is to provide immediate service over a large mileage regardless of the final cost of such a program to the community. This policy requires an extremely heavy maintenance burden and frequent reconstruction. For the first few years it apparently accomplishes wonders but in a short time the roads begin to go to pieces faster than they can be rebuilt and it becomes impossible to expand the mileage of improved roads as all the funds are required for renewals. It is not possible to get very far in this way for heavy traffic roads but it has some merit for the purely local roads and is sound policy in thinly settled pioneer or purely agricultural districts.

General Utility Policy.—The third policy (General Utility) advocates the construction of moderately good, moderately low priced pavements (including gravel, water-

bound macadam oiled, bituminous macadam and a small mileage of rigid pavements) appropriate to the different volumes of traffic to which the roads are subjected. It advocates efficient maintenance of such improvements. It advocates small expenditures for patrol maintenance and minor betterments to make the best temporary use of the existing roads. This policy gives more immediate traffic service over a larger mileage for limited funds than obtained by the boulevard policy and eliminates wasteful expenditure on excessive maintenance or too frequent reconstruction introduced by the cheap pavement policy. Its success depends on the efficiency of maintenance. The supporters of this policy know that maintenance has been well handled in some cases and insist that it *must* be well handled if a good general highway system is ever achieved. This policy advocates the original construction of the improved roads up to Standards of General Utility by general taxation; the maintenance and renewal of the main roads by vehicle taxation; the immediate temporary improvement of gaps on the main roads by vehicle taxation and the maintenance and renewal of local roads by a graduated general tax. It is usually possible to expand the system gradually under such a distribution of the burden without losing the effectiveness of the previously improved roads. The General Utility Policy seems to have considerable merit for most localities. The principles of applying this policy are summarized at the end of the chapter, page 61.

Need for Economy.—Even the most casual analysis of the national road problem as it exists today (1922) leaves a very definite impression that caution must be exercised to keep high priced boulevard construction to a minimum of miles, where it is absolutely needed. It is unfortunate that it is necessary to advise caution in connection with highway expenditures. Such action is never popular and its need is rarely appreciated until after the damage is done. *Most communities are in a class with the small boy whose mother said, "Johnny, if you eat any more, you will explode." "Never mind, Ma, pass the pie and get out of the way."* There is, however, enough definite evidence in regard to the cost of construction and upkeep of high class modern highways and in regard to the failure of even rich communities to keep them in good repair to warrant caution in inaugerating programs involving too much perfection of travel comfort over a large percentage of the total road mileage. Pavements permitting year round use for moderate loads with moderate comfort are an economic necessity. Additional comfort and strength is a desirable refinement. A definite analysis of a rich district is given pages 49 to 57 showing the necessity for caution.

Field for Economies.—The almost universal lack of entirely adequate funds that can be properly apportioned to any specific road improvement makes it necessary to economize on some details of the design. As discussed in the first book of this series, it is certain that reasonably good location, grading and drainage must not be slighted as they are the permanent elements of the improvement. *Where economies are necessary, they may well be confined largely to the items of excessive refinements of location and pavement design. It is not permissible to sacrifice adequate pavement strength for reasonably regulated traffic, but economy in the*

elements of width and perfection of surfaces is justified. Excessive refinements in either location or pavement construction should be restricted to special service heavy traffic roads in rich districts. A definite illustration of the application of reasonable economy is given in official reports, pages 153, 159, 477.

Administrative Considerations.—The province of administrative highway engineering lies in determining how much the community needs for highway purposes, how much it can reasonably raise and how this amount can be best spent to give the most service to the travelling public. It cannot properly consider one road as an isolated problem; it should not overemphasize the importance of the improvement of the main roads to the exclusion of reasonable treatment of the feeder roads as each road or class of roads is an integral part of traffic service for the entire district.

Sound administrative policy is based on the relation of the service value of highways to permissible maximum tax rates, the distribution of the tax burden, the raising of funds for construction and maintenance, the requirements of traffic, the necessity for regulation of traffic, the layout of systems, the classification of roads as to their relative importance, the order of construction and finally the stipulation of what is a reasonable limit of expenditure (considering the entire problem) for the special project under immediate consideration. *The engineering design should conform to this limit.*

Basic Administrative Principles.—The detail discussion is taken up later in the chapter but at this point, it is just as well to emphasize two basic principles.

1. *Communities are usually best served by the policy of Progressive Improvement.*
2. *There should be a well-defined relation between the general character of the highway system and the method of taxation.*

Progressive Improvement.—Progressive improvement is defined as a series of improvements which gradually raise the effectiveness of the highway from a poorly graded and drained earth road to a high class modern pavement. This method has the advantage of giving the best possible immediate service to traffic that can be accomplished with limited funds. It has the disadvantage of raising the total final cost, as a series of operations is always more expensive than one complete job. However, if foresight and a set plan is adopted at the start, each step of the improvement can be utilized as a part of the final result which eliminates most of the waste introduced by the prevalent system of a series of unrelated work which at each step tears out more or less previous work. Very excellent systems of progressive improvement have been inaugurated by a number of the states which are handicapped by low assessed valuations, one example of which is shown Fig. 4.

Even in the richer states, the policy of progressive improvement is necessary for a portion of the mileage and in the poorer districts it must often be carried to quite extreme lengths. It is, however, generally sound policy, considering the cost of traffic operation, as the saving in traffic cost due to the rapid completion of moderately good year round roads far outweighs the added final cost of construction introduced by the necessity of reconstruction up to higher standards of comfort. The variation in the application of this policy may be indicated as follows:

It is quite generally recognized, for districts where the roads are largely unpaved, that the most important result to be achieved is to make the entire

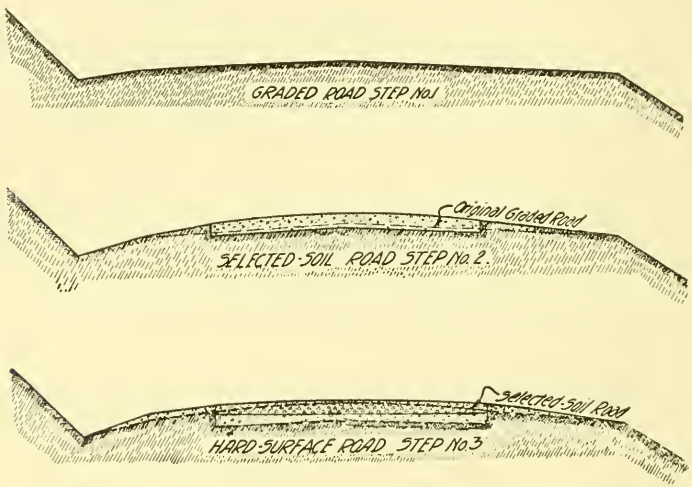


FIG. 4.—North Carolina progressive improvement.

system usable the year round for moderate loads and that the quicker this is accomplished the better it is for the community.

Where a district has brought traffic "out of the mud" by a complete system of moderately serviceable roads, further improvements should consider only a proper economic pavement design suitable for expected traffic. The element of time is not vitally important.

In the first case, relatively poor pavement surfaces are often necessary in order to eliminate mud roads with available funds but the location, grading and drainage must be up to the final standard. The surface can be improved later under reconstruction programs up to standards providing more comfort and convenience for traffic. Inconvenient, narrow pavement surfaces are often justified as temporary expedients but it is rarely allowable to build structurally weak pavement foundations unsuitable

for year round use of moderate loads (2½-ton trucks) in order to get mileage.

In the second case, where most of the roads are serviceable and some are excellent, there is very little real economic loss through a little minor inconvenience to traffic in the matter of dust or roughness on a portion of the highways. It is permissible to extend a reconstruction program over a more or less indefinite period but the element of time is still important. Under these conditions where the funds are inadequate for completely finishing the system with truly economic roads, the mileage for immediately available funds may better be cut rather than again distribute the funds over the entire system.

Effect of Tax.—It is desirable of course for the original legislative plan to tax the proper sources for the kind of highway system the community needs. As a matter of fact in the desire to raise the money any available source of revenue is used and large bond issues are authorized to be paid for either by general taxation or by vehicle taxation or by combinations of the two. No broad plan of construction is contained in many of these authorization laws and successive administrations which expend the funds adopt radically different general policies. The same bond issue may be partially spent under the cheap Pavement Policy, partially spent under the Boulevard Policy and finished up under the General Utility Policy. It is therefore just as well to consider the source of the money in deciding on the basis of expenditure.

If a construction program is financed by a general tax levy, it seems good sense to use the funds for the rapid construction of a fairly complete general utility system of highways suitable for the average road user. It is no more than reasonable to restrict the character of pavements, other design features and traffic loads to the limit required for the general community benefit. That is, extreme refinements either of location or pavement design or extreme traffic loads are of very little benefit to the community at large except for a comparatively small mileage of special service roads and there seems to be no reason why it should bear a needlessly high construction or maintenance burden on secondary roads for the benefit of a small percentage of the actual road users.

If a reconstruction program is financed by direct graduated vehicle taxes of which trucks pay their fair share a much higher type of pavement, more refinements of location and greater freedom of movement for exceptionally heavy loads are permissible and are in fact undoubtedly justified considering the economic hauling requirements of special industries. Such funds may also properly be used largely for main road construction without much consideration of purely local roads. That is, large expenditures for a limited mileage of special roads may be justified.

This principle of the limitation of expenditure depending on who foots the bill is not particularly popular in various quarters. There is no

apparent reason, however, why exceptionally heavy truck haulage should be subsidized by a general tax levy. If any industry cannot stand its share of a reasonable highway trackage charge, made necessary by the type of vehicle it is using, and still compete with other carriers which provide and maintain their own trackage, it is sound business to restrict that industry to a lighter type of vehicle. This, however, does not normally affect a large number of road users, as discussed under traffic requirements. It is quite natural that active propaganda has often obscured the relative extent and value of this type of haulage and saddled road districts with an extreme burden in connection with the construction or maintenance of secondary and local roads. It is, however, entirely unnecessary to permit minority interests to continue in control of fundamental policy.

Ordinary Administrative Practice.—Before taking up the detail discussion of administrative theory, it is, perhaps, just as well to summarize the progress which has been made and the common faults of existing administrative practice.

Theoretically, the problem is complex but subject to quite logical engineering analysis. Practically, the solutions only give minor consideration to the technical slant. During the past fifteen years the routine technical details of design and construction have made rapid strides and have reached quite excellent standards. During this period, general administrative procedure has shown some net improvement but we all get a little impatient at times that the progress is not more rapid. Highway administration is handicapped by the difficulty of attempting to reconcile the conflicting interests of special favor and general community benefit. Considering this fundamental difficulty, the results to date are remarkably good and may be summarized as follows. Standards of design and construction have been radically improved. Finance and tax methods have advanced as shown by the tendency to eliminate long term sinking fund bonds and the adoption of more rational motor taxation but the relation of the amounts raised by means of general taxation and direct traffic tax needs further consideration. Traffic regulation based on engineering recommendations is receiving some legislative attention, but the laws have been half-heartedly enforced in many cases. Pavement type selection is open to radical improvement from the standpoint of real community benefit. The layout of systems and the order of construction of the roads are still largely administered with an eye on the next election. The personnel of the engineering and maintenance organizations is given very little incentive for clean cut efficiency or for enthusiastic regard for real community service, the main difficulties being short tenure of executive office, civil service limitations and niggardly pay.

The intention of this book is to present the problem from the standpoint of the Designing and Constructing Engineer, and it is safe to say that the greatest difficulty they have to contend with lies in the general attitude, which, from lack of a better term, will be called the *hypocrisy of administration.* The point of view expressed as follows is intended as constructive criticism and not in any sense as a destructive argument. Construction engineers are making an uphill fight and their point of view is entitled to consideration. We have seen so many promising young engineers ruined by this administrative fault that it seems well worth while to state the facts without mincing words. When they say that the main difficulty lies in hypocrisy, they refer to the following common procedure:

Highway departments adopt for publicity purposes platforms composed of very excellent general principles of finance, design, construction and theoretical organization and then proceed to violate these principles in varying degree with clockwork regularity. That is, the actual working of the popular slogan of "Economy and Efficiency" as applied to many highway departments is quite accurately expressed by the old nursery rhyme.

> "Now there is no such thing as a Ginko Tree.
> There never was, though there ought to be
> And its also true, though most absurd,
> There is no such thing as a Wallabye Bird."

The engineers in the organization are told to hold strictly to the principles and detail procedure publicly expressed and then the organization is either purposely or inadvertently crippled so that it is impossible to carry out the publicly expressed directions. Care is usually taken not to cripple effectiveness to the danger point of easily detected inefficiency but all the experienced engineers know what is going on and realize the tremendous waste of public funds resulting from the lack of moderately effective organization. Where public criticism does occur, the departments point to their enormous file of general circular letters and public utterences which are eminently correct and say that they have done everything humanly possible to carry out an effective program for the benefit of the community. Luckily at times an unusual combination of circumstances makes it possible for a high class executive to carry out an effective program and it is during such periods that most advances in practice occur. These advances are rarely completely lost as the standard set is hard to discredit and dangerous to lower. There are many cases where inexperienced executives intend to develop efficient organizations but fail on account of ignorance of the requirements and disloyalty of subordinates but the quite common and continuous condition of radical disagreement between the publicly expressed policy of public

service and actual performance of inefficiency and more or less special favor cannot be charged to ignorance and it is against this tendency that engineers may well throw their influence. For the benefit of the younger men, it is, perhaps, just as well to outline the indirect methods used to cripple organizations without apparent intention and to suggest a very simple method of procedure which even the subordinate engineers can use with some effect in minimizing insincerity and indirection in administrative action.

The following general indirect methods are often used to reduce efficiency of organizations and to increase the ease of granting special favor. The responsible highway executives are not usually in favor of this stuff but it is forced on them by our system of public work for which the community at large is definitely to blame.

1. The adoption of low salary standards for engineers and inspectors ostensibly on the score of payroll economy for the benefit of the dear taxpayer but actually because mediocre talent is desired as it can be more easily manipulated.

2. The adoption of the policy of too small a force of high grade well paid engineers and inspectors which overloads the good men with work and gives them no chance for really effective supervision. This policy sounds fine in producing the impression that an earnest effort is being made to utilize high grade talent but the result approaches zero in actual effectiveness.

3. The policy of demanding plans and estimates on such short notice that there is no possibility of giving them reasonable thought and care in preparation. A very conservative estimate of the loss due to such action has often been 5 to 10 per cent of the cost of large programs.

4. The policy of placing inexperienced young engineers in charge of large contracts where there is no possibility of their being really effective which encourages the practice of Court of Claims contract extras.

5. The transfer of efficient engineers and inspectors who are rigidly enforcing specifications not intended to be rigidly enforced on certain jobs. Luckily this method is losing its popularity.

6. The general policy of failing to keep accurate records of the performance of various types of pavement and the cost of maintenance and in general, befogging the finance and pavement problem from lack of definite data.

Where these policies are adopted purposely, the administration is anxious to conceal the real workings of the system and all the older engineers understand that a very effective way to combat objectionable results is to record procedure in written form. In almost all cases, definite written decisions and orders which state plainly the actual result which is occurring and the reason for its occurrence protects them personally and stops its application for the particular case in question.

Engineers naturally object to being used as tools for special favor, particularly if they must take the blame, and for the benefit of the younger men a few definite suggestions are made.

There is no reason for being unduly suspicious but it is well to keep your eyes open for procedure of this kind and to draw the line at the proper point. Loyalty and cooperation with your organization and immediate chief are essential and are generally justified from a personal standpoint but if you become convinced that you are being made a tool of indirect methods of granting favors, it is not good policy to compromise with the principle of effective public service. The experience of the older men indicates that the following ordinary every day procedure is desirable.

Specifications and explicit directions must be rigidly enforced. If they are impracticable or needlessly harsh, the remedy lies in changing the specifications or instructions and not in easing up on the enforcement. If the constructing engineer receives verbal instructions to ease up, the safest procedure is to write a definite letter to your chief stating what verbal orders have been received and from whom received and that you are carrying them out. A simple statement of fact is sufficient. If the change is justifiable, a definite record does no harm; if the change is unjustifiable, a definite statement of procedure in writing as a matter of official record generally has the beneficial effect of revocation of the order. This is a matter of common experience.

If you are working short handed and feel that proper supervision cannot be given to the work, it is good policy to write an official letter to your chief stating that you cannot be responsible for the character of the construction unless your inspection force is increased either by additional men or more intelligent help. There have been innumerable cases where with full knowledge of conditions reasonable inspection was denied until action of this kind was taken and at once proper inspection furnished. There are many cases where through actual shortage of men additional help cannot be furnished but it is desirable to go on written record for your own protection.

If plans are demanded on short notice, it is often necessary to meet the time limit but the engineer should accompany the half-baked result with a simple written statement that it is possible by further study to produce a more effective or economical design.

It is desirable to encourage the younger men to adopt the policy of definite written orders and reports officially recorded. It is not only a safeguard but encourages them to consider carefully before making decisions. It clarifies their own ideas and is a distinct help to their chief if he wants good results. If good results are not desired, this method causes friction and temporary trouble but trouble is not an undesirable episode under certain conditions and we rather enjoy it whether we get licked or not. An occasional licking is most certainly preferable to being

known as "Alibi Ike" or to having the motto of "Peace at Any Price" pinned on to your reputation.

On the other hand too many of the subordinate engineers are soured by minor imperfections of procedure. They dissipate their energy in merely antagonistic criticism. This gets nowhere. What counts is what they advocate, not what they oppose. Results are obtained by the affirmative, constructive, mental attitude which having decided on a desirable solution demands action as near the ideal as can be obtained at the moment but will not compromise on fundamental essentials which are merely insistence on good work, regardless of pressure; on fair statements of fact, regardless of pressure; and on common honesty, regardless of pressure. They have little to do with technical knowledge.

Very few engineers have any direct influence on the broad policies of taxation, traffic regulation and the selection of type but they can exert considerable indirect influence by discussing the problem publicly or by ordinary discussion with people they meet in daily contact. It is certainly well worth while for the student to consider the factors and to formulate general policies he is willing to support. The detail discussion of administrative theory follows under the headings of:

1. Value of Highway Improvements.
2. Distribution of the Tax Burden.
3. Traffic Requirements.
4. General Suitability and Final Cost of Pavement Types.
5. Classification of Roads.
6. Order of Construction.
7. Financing the Improvements.
8. Example of Administrative Analysis of Reasonal Expenditures.
9. Research and Records.
10. Organization Personnel.

GENERAL VALUE OF IMPROVED ROAD SYSTEMS AND THE ECONOMIC HAULING VALUE OF PAVEMENTS

The value of a highway system is measured by both its direct and indirect benefits. A complete system of highways usable the year round for *reasonably regulated traffic* raises the living standard of the community as well as paying for itself directly by reducing the cost of travel. Some of the benefits of a complete network of roads are listed as follows:

1. They provide lines of communication to all parts of the district and save time of travel.

2. They provide direct contact hauling service to all parts of the producing area of the district for the entire year.

3. They make rural life more attractive and tend to stabilize a healthy ratio of rural and city population.

4. They increase the social and recreational possibilities of both city and rural residence.

5. They increase the flexibility and strength of the general transportation system of the county in times of unusual stress such as military use in time of war and emergency transportation in case the railroad systems are tied up by strikes or otherwise.

6. They raise rural land values.

7. They decrease the cost of short hauls on farm produce.

8. They increase the range of marketing both in respect to distance and favorable selling periods.

9. They decrease the cost of moderately long haul for some commercial products up to say a 100-mile distance in competition with railroad haul and for certain commodities up to perhaps a 200-mile distance.

It is self evident that a complete system of general utility roads either directly or indirectly benefits everyone in the community. It is not necessary to put an exact money value on the benefits derived. Even if the direct money return of reduced hauling expense is ignored the more or less intangible benefits of items 1 to 5 would justify any necessary expenditure to obtain a complete system suitable for the needs of the community at large. *These general community benefits depend, however, very largely on the factor of the completeness of the system for the average user and not on extreme refinements of construction.* These benefits are very largely reduced by inadequate mileage or delay in bringing the entire system up to a moderately good standard.

The community at large derives its return on highway investment by providing traffic service for the average user. It derives very little real return on additional expenditures made necessary for the convenience of a small number of exceptional users. As a matter of fact, the reduced cost of hauling does not particularly impress the average user; even the farmer in hauling produce thinks more of his saving in time, added range of market and continuous ability to haul than he does of a ton mile reduction in cost.

If, however, the value of a road system is considered entirely from the standpoint of economic travel benefit, it is certain that this feature alone will amply justify the construction of a moderate priced general utility system *but it is doubtful if a further raise in general standard on moderate traffic roads can be justified for the benefit of a few exceptional users.*

Economic Hauling Value of Pavements.—The economic hauling advantages of improved location and grade reductions were analyzed in the first book of this series (Highway Location, Grading and Drainage). For the convenience of the reader pages 154, 477 and 581 give official reports showing the value of grading and relocations and the method of comparison. It is not necessary at this point in the discussion to more than state that the capitalized value of such improvements at 5 per cent

probably ranges between $10 and $50 per foot of distance saved (depending on the character of the traffic) for an average volume of traffic of 100 vehicles daily and a value of between $5 and $1,400 (depending on the character of traffic and rate of grade) for saving 1 foot of rise and fall for a volume of traffic averaging 100 daily. (See Figs. 5 and 5A.)

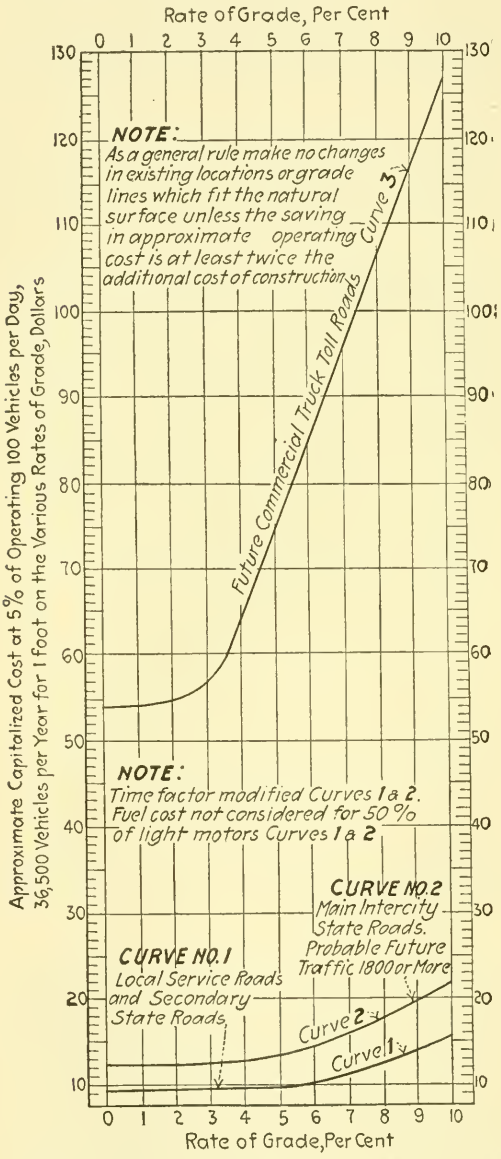

Rate of Grade, Per Cent
0 1 2 3 4 5 6 7 8 9 10
Approximate Capitalized Cost at 5% of Operating 100 Vehicles per Day, 36,500 Vehicles per Year for 1 Foot on the Various Rates of Grade, Dollars
NOTE:
As a general rule make no changes in existing locations or grade lines which fit the natural surface unless the saving in approximate operating cost is at least twice the additional cost of construction.
Curve 3
Future Commercial Truck Toll Roads
NOTE:
Time factor modified Curves 1 a 2.
Fuel cost not considered for 50% of light motors Curves 1 a 2
CURVE NO.2
Main Intercity State Roads.
Probable Future Traffic 1800 or More
CURVE NO.1
Local Service Roads and Secondary State Roads.
Curve 2
Curve 1
Rate of Grade, Per Cent

FIG. 5.—This graph indicates an approximate basis for comparison of alternate locations and grade design. The capitalized operating cost is based on a volume of travel of 100 vehicles daily for 1 foot of distance on the various rates of grade assuming that ½ the travel is up hill and ½ down hill.

The economic hauling value of pavements has not been definitely established nor is it possible to establish this or forecast future costs with any degree of exactness, but a reasonably close estimate can be derived for purposes of a general conclusion. Considerable experimental work to determine the economic value of hard surfaced pavements is being carried on. The data is useful in a general way but must be used with caution as it is extremely difficult to apply experimental values to the wide range of traffic and pavement conditions on the ordinary road at different seasons of the year or to forcast changes in fuel costs, engine efficiencies, etc.

In comparing earth roads with various other pavements such as gravel, modern macadam and rigid pavements, the special condition of an impassable earth road in wet weather or ideal conditions in dry weather are ignored and average conditions accepted. It is assumed also that each type of road is well

maintained and structurably able to hold the traffic load. Under these conditions there is some difference in the wear and tear on mechanical equipment in fuel consumption and in speed of travel. This difference depends on a number of factors but the type of pavement and its general condition are the main factors. Macadam or gravel in excellent condition require less fuel consumption than where they are poorly maintained. New smooth rigid pavements require less fuel than they do as they age and develop imperfections of surface. Rigid pavements in their last stages before reconstruction are worse than macadam are generally permitted to become because they are so expensive and difficult to repair that more inconvenience is tolerated for a longer time than is usually permitted on easily repaired macadam.

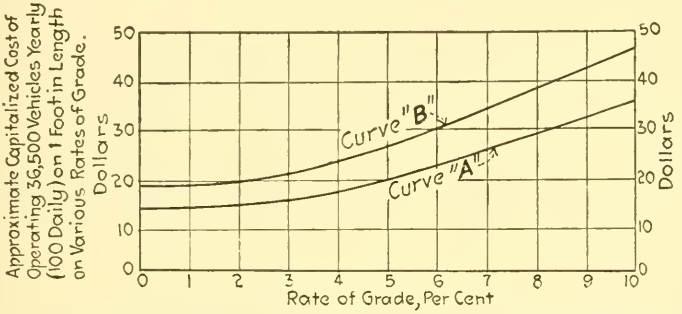


FIG. 5A.—This graph illustrates the approximate effect of dangerous alignment on motor operating costs. (Time factor included) Curve A safe alignment. Curve B dangerous alignment (see Highway Location Grading and Drainage page 141 for discussion.)

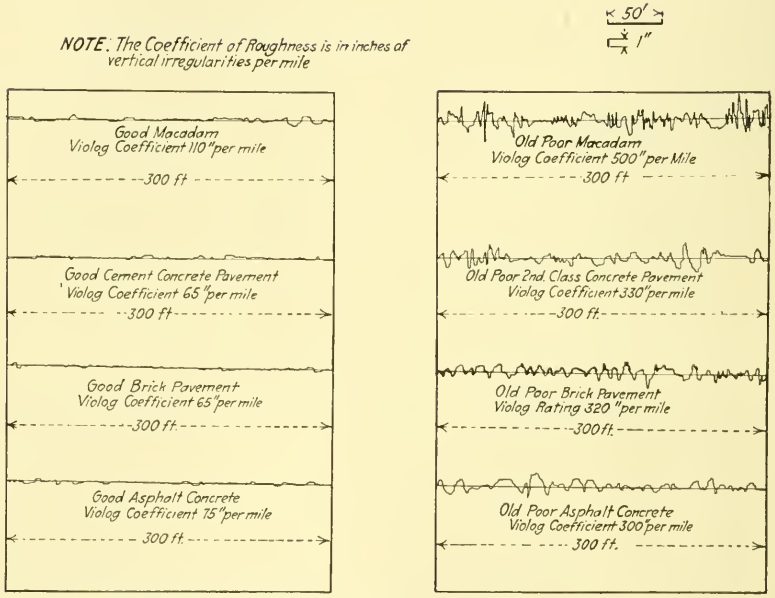
TABLE 1[1]

Kind of pavement	Rolling resistance in pounds per ton of load (level grade)	Kind of pavement	Rolling resistance in pounds per ton of load (level grade)
Asphalt	30 to 70	Macadam roads	20 to 100
Brick and concrete	15 to 40	Plank	30 to 50
Cobble stones	50 to 100	Stone block	30 to 80
Earth roads	50 to 200	Wood block	30 to 50
Gravel roads	50 to 100		

The accompanying vialog charts show the wide range in surface roughness of pavements of all types due to age (see page 18).

Table 1 shows the variation in resistance to the movement of loads on various pavements. It indicates a wide range for each kind of pavement. It may well be that under favorable condition an earth road well maintained may actually offer less resistance than an old rigid pavement

[1] BAKERS, "Roads and Pavements."



NOTE: This Chart illustrates graphically the wide range in surface roughness with attendant resistance to traction on all Standard Pavements due to age and lack of effective Maintenance. The practical use of the Violog in connection with Highway Programs is discussed in Chap 2. A reasonable allowance for increase in business motor operation cost due to roughness is approx. $80 per mile per year per 100 vehicles average mixed traffic daily (36,500 yearly) for each 100" increase in Violog Coefficient.

CHART A.—Vialog records of surface roughness (showing effect of age).

but for average conditions there is a well-defined advantage for gravel over earth and macadam over gravel but a comparatively small advantage for rigid pavements over well-maintained modern macadams.

Tables 2 and 2B reinforce this statement by showing actual fuel consumption. The tests were made by the White Company, Cleveland, Ohio, in cooperation with the Portland Cement Association and by the Iowa State Experimental Station at Ames under the direction of Prof. Agg and Mr. Goldbeck of the United States Bureau of Roads.

TABLE 2.—WHITE COMPANY DATA

Type of road	Miles per gallon (2-ton truck)	Type of road	Miles per gallon (2-ton truck)
Earth	5.78	Fair brick	9.88
Fair gravel	7.19	Good brick	11.44
Good gravel	9.39	Good concrete	11.78
Fair bituminous macadam	9.48		

Allowing for the difference in classification as fair or good the following values are reasonable for comparative purposes.

TABLE 2A

Type of road	Gallons per ton mile	Miles per gallon (2-ton truck)
Earth (average condition)	0.083	6.0
Gravel (average condition)	0.059	8.5
Macadam (average condition)	0.048	10.5
Rigid pavements (average condition)	0.046	11.0

TABLE 2B.—GASOLINE CONSUMPTION DETERMINATIONS[1]

Run	Kind of road surface	Distance traveled miles	Ton-miles per gallon of gas
1	Gravel—some soft places	60.0	19.8
2	Gravel—hard and smooth	51.0	21.7
3	Gravel—after summer shower	6.0	18.5
4	Gravel—hard and dry	10.5	21.9
5	Gravel—after summer shower (same road as run 4)	10.5	19.0
6	Gravel—hard and smooth	71.0	22.0
7	Monolithic brick in excellent condition	10.78	29.4
8	Same as run 7 on another day	10.78	30.0
9	Portland cement concrete—excellent condition	68.0	30.7
10	Bitulithic, excellent, in August	13.0	22.7
11	Bitulithic, excellent in September	8.0	24.3

[1] T. R. AGG, *Eng. News-Record*, Dec. 7, 1922.

AVERAGES FOR ALL RUNS

Type of surface	Gallons per ton mile	Ton-miles per gallon of gas
Earth (generally in poor condition)	0.07	14.0
Gravel	0.05	21.2
Monolithic brick	0.03	29.7
Portland cement concrete	0.03	30.6
Bitulithic	0.04	23.4

RELATION BETWEEN FUEL CONSUMPTION AND TRACTIVE RESISTANCE

Type	Source of data			Relative tractive resistance
	Ames	*Canadian Engineer*	A. N. Johnson	
Good pavement	1.00	1.00	1.00	1.00
Macadam and bituminous macadam	....	1.23	1.24	1.20
Gravel	1.43	2.1	1.64	1.6
Earth	2.10	2.03	2.04	2.20

These data and the discussion in Chap. II indicate that considerable fuel saving (probably 50 per cent) is effected by improving the road from soft earth to a firm surface but that very little saving (possibly 3 per cent to 5 per cent) is effected by raising the standard of pavement construction beyond that of well maintained modern macadam to rigid pavements. Recent laboratory investigations indicate considerable difference in tire wear on different surfaces with a distinct advantage for the high type smooth surfaces but such experiments are based on quite ideal conditions of surface and do not consider surface deterioration, which occurs on all types and which in a short time tends to reduce the apparent advantage of the more costly pavements, nor do these experiments consider the factor of snow and ice for a large part of the year. It is not likely that tire wear or gas consumption will have much practical effect on type selection where the choice is confined to the higher type modern macadams as contrasted with rigid pavements. This conclusion is borne out by common experience and observation. The arguments for rigid pavements derive their strength from considerations of maintenance under exceptionally heavy special traffic conditions and the fact that less interruption of traffic occurs on account of fewer maintenance and repair periods and the less frequent necessity for detour. The possible minor differences in fuel

consumption between different high type pavements are discussed in Chap. II.

Figures similar to those of Table 2 for fuel consumption and what data is available on tire and engine wear do not warrant placing an exact travel value on pavement construction but a conservative estimate of such saving considering fuel, time and depreciation of equipment for modern macadam or rigid pavements over well maintained earth roads may be assumed as about $0.01 per mile for the average pleasure vehicle and about $0.01 per ton mile for trucks. This travel cost-saving due to pavement plus the operation savings due to better location and to grading improvements must at least equal the yearly cost of the road, in order to justify the improvement from the standpoint of travel economy. The yearly road charge includes interest on the total construction investment (including grading, drainage and pavement) and also the annual charges for maintenance and renewal of the highway surface.

Anticipating the discussion of maintenance and renewals, it is reasonably certain that if a road is properly designed, fairly well maintained and that the general type of surfacing used is suitable for the traffic the road must carry, that the yearly cost to keep it continuously in serviceable condition, depends on the character and volume of traffic and that minor variations in pavement type have little effect on final cost. This total yearly charge assuming interest on the total original construction cost at 5 per cent amounts to from 7 to 12 per cent of the original cost of the road for all types of roads that would normally be used for a general utility system. The data is developed in detail in Chap. IV on Maintenance and Renewal.

This is of course subject to some variation as later discussed but for average road conditions it is not a misleading assumption for the purpose of deriving a rough approximation of the maximum allowable construction cost based on the factor of travel cost saving. Table 3 is compiled on this basis. Figures of this kind are only intended for deriving average expenditures on a large mileage as there will always be short stretches of road necessary for the completion of a system which may greatly exceed average costs per mile due to exceptional conditions of grading, material costs, etc.

In order to show what these figures mean in terms of a general conclusion, it is necessary to compare them with the construction costs of modern highways suitable for different volumes of reasonably regulated traffic (see Table No. 4). By suitable is meant roads of ample strength, convenience and safety, serving traffic with moderate comfort and having a general type of pavement surface which can be economically maintained.

A comparison of Tables 3 and 4 indicates in a general way:

1. That on roads carrying an exceptionally heavy traffic, the actual travel saving will more than justify high grade types of construction.

TABLE 3.—ALLOWABLE COSTS (1921 COST CONDITIONS)

Average daily number of vehicles	Assumed yearly travel cost saving Based on $0.01 per vehicle mile, average mixed traffic	Maximum allowable expenditure per mile for original construction based on pavement benefit	Reasonable expenditure with some profit to the community
100	$ 350	$ 3,500	$ 2,300
200	700	7,000	4,600
300	1,050	10,500	6,900
400	1,400	14,000	9,200
500	1,750	17,500	11,500
600	2,100	21,000	13,800
700	2,450	24,500	16,100
800	2,800	28,000	18,400
900	3,150	31,500	20,700
1,000	3,500	35,000	23,000
1,500	5,250	52,500	34,500
2,000	7,000	70,000	46,000
3,000	10,500	105,000	69,000
4,000	14,000	140,000	92,000
5,000	17,500	175,000	115,000
10,000	35,000	350,000	230,000

Column 3 represents maximum allowable expenditure. If construction equals this amount, the community gets no money return on their investment; they merely take their money out of one pocket and put it in the other. It is therefore, not desirable to use more than two-thirds of these amounts if a profit is considered desirable; column 4 has been figured on this basis.

2. That for moderate traffic (say 300 to 1,500 average vehicles per day) satisfactory general utility highways are justified but needless refinements may well be avoided if any real return on investment is desired.

3. That for purely local roads carrying less than say 300 vehicles per day it is probably necessary to consider the intangible benefits to justify a satisfactory standard of construction. This is shown in chart form on page 24 and begins to help in the matter of tax burden distribution.

Summarizing the limitations imposed on expenditures by the value of highways; if Fig. 6 is modified slightly to fit actual observed road service, it is evident that *if construction investment is considered from the standpoint of direct return by reduction in cost of vehicle operation we are limited to the standard of general utility except for heavy traffic roads carrying an average volume of over say* 1,500 *vehicles per day.* This class of road represents a very small percentage of the total road mileage. Even for roads carrying a year round average of more than 1,500 vehicles per day, there is no practical advantage in adding much to the amounts shown by the general utility curve.

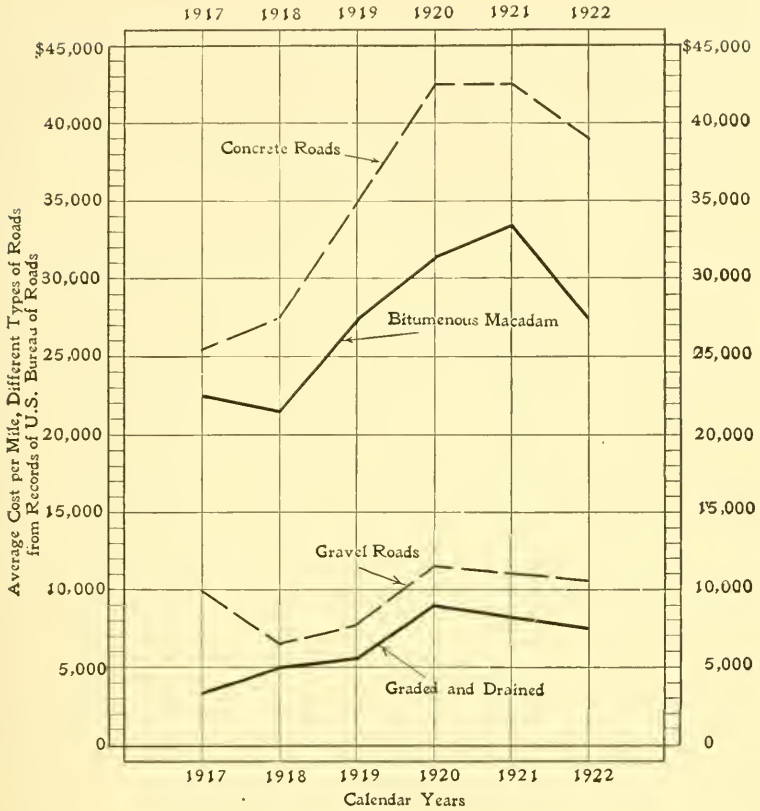


TABLE 4.—NECESSARY COSTS

Approximate volume of traffic per day, 10-hour count in summer season	Approximate construction cost per mile including grading, drainage and pavement (1921 cost conditions)
0 to 300	$2,500 to $10,000
300 to 800	10,000 to 20,000
800 to 1,800	20,000 to 30,000
1,800 to 5,000	30,000 to 50,000
Above 5,000	50,000 to 70,000

Table 4 costs include grading, drainage and pavement. For the ordinary road where the grade line follows the natural surface, the item of grading is largely necessary to provide a suitable roadbed for the pavement and is properly a pavement charge. Where hills are cut down and distance shortened the economic value of such work should be added to the values given in Table 3 before comparing with Table 4, see official report page 158.

If construction investment is considered from the standpoint of intangible benefits expressed in terms of convenience, safety, pleasure and ease of communication, no practical limitation of expenditure except that imposed by the community's financial ability to complete a general utility system within a reasonable time need be considered.

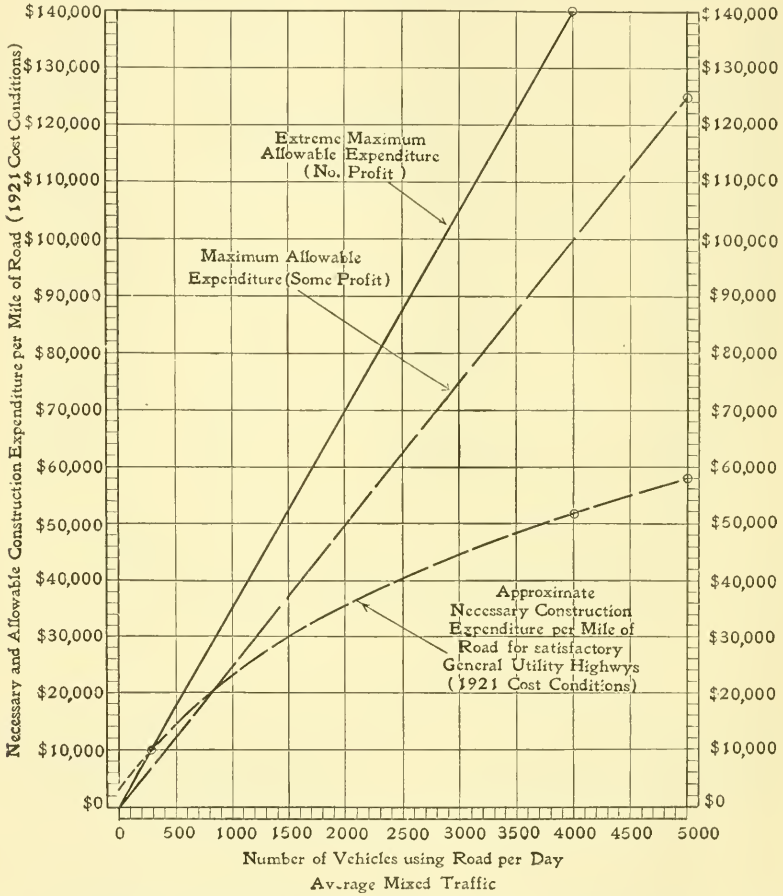


FIG. 6.—Graphic comparison of allowable and necessary construction costs. (Based on Tables 3 and 4.)

The tax burden distribution also has a distinct bearing on the proper limitation of expenditure.

Distribution of Tax Burden.—A successful tax is based on three main points:

1. The final burden should fall on each individual as nearly as possible in proportion to the direct and indirect benefit received.

2. The direct tax should be paid by the individuals receiving the immediate direct benefit if they are financially able.

3. The tax must be levied on a definite source comparatively easy to assess and be collected from individuals having the ready money for payment.

Real property, motor vehicles, tractor and horse vehicles and gasoline are definite sources of taxation owned or used by individuals presumably with ready cash to pay any reasonable tax burden.

The immediate and direct benefits of improved highways are largely received by the owners of vehicles operating on the roads.

The final direct and indirect benefits of a modern highway system were given on page 14.

While the road user gets most of the direct benefit, it is rarely feasible in the first stages of the improvement to tax him directly for a large proportion of the cost of construction. That is, before improved highways are an accomplished fact, the vehicles are fewer in number and operated by financially poorer individuals. The completion of a modern highway system increases the number and effectiveness of vehicles and adds to the ability and willingness of the owners to assume a larger tax burden. It is therefore generally believed that the original construction of such a modern general utility system (*under a proper classification based on reasonable regulation of traffic*) should properly be paid for largely by a general tax levy which is eventually quite evenly distributed over the community.

The cost of maintenance and the renewal of pavements depends on the volume and kind of traffic. The largest share of the benefit of keeping a road continually in excellent shape goes to the vehicle owner. There are two general classes of traffic, pleasure traffic and business traffic. If a pleasure vehicle is taxed a fair amount to cover the damage it does to the road, this is a luxury tax borne by the owner. If a business vehicle is taxed a fair amount to make the highway self-supporting, the charge is added to the other vehicle operating costs which go into the price charged to the consumer and the public at large foots the bill. The principle of a vehicle tax for maintenance and renewal apparently has a sound basis in fairness. While there may be minor flaws in its application, there are the same flaws in the application of a tax principle which is not essentially sound so that the small practical inequalities of the tax do not invalidate the soundness of the general proposition.

It is certain that if maintenance and renewal were paid by general tax levy that pleasure traffic would escape its fair luxury tax and the business traffic particularly heavy hauling would have an unfair advantage in competition with other transportation methods which pay their own cost of track or waterway construction and maintenance.

Public road tolls are not feasible except for a few special cases, as they restrict the free movement of traffic, so that some form of graduated vehicle license based on gross vehicle and load weight and type of tire supplemented by a gasoline tax seems the most reasonable form of tax for the upkeep and renewal of at least the main highways.

These general principles expressed in terms of definite policy are as follows:

It is quite generally recognized that the intangible benefits of a road system practically obligate the community at large to construct such roads up to the standards of general utility by means of a general tax levy. This can be accomplished without exceeding the bounds of reason on the basis of a fairly reasonable length of time for the construction program and the use of reasonable length of term of serial bonds for raising construction funds.

The direct and intangible benefits accruing to vehicles using the highways practically warrant putting upon the owners of vehicles the cost of maintaining and renewing at least the main roads of such a system after it has once been built. For the purely local roads which are not self-supporting due to light volume of traffic (see page 22) it is not reasonable to tax vehicles for their entire maintenance and upkeep. That is, vehicle license fees plus gasoline tax should probably be figured on the basis of taking entire care of the main roads, aggregating not over 15 to 25 per cent of the total road mileage, and for raising the standard of such roads beyond that of general utility. For the purely local roads a small percentage of the maintenance cost can be properly charged against traffic. This can be accomplished by a graduated license fee and gas tax not beyond the bounds of reason. For a completed system in a well settled area, it is probable that an average yearly tax of from $25 to $50 per vehicle will produce the necessary funds. Considering the mileage run by the average car and the variations in license fees increasing rapidly for commercial trucks, this would not be an excessive amount. The present motor license averages about $8 (1920). Prevailing gas tax rates for 1922 are given on page 47.[1]

The raising of funds for immediate temporary traffic service over the gaps in the existing improved road system may well be raised by a slight addition to the vehicle tax; this affords no difficulties as the immediate return to traffic is so self-evident that road users generally are in favor of such procedure. This tax gradually decreases as the system is completed, balancing the normal increase in the regular maintenance tax.

While it seems reasonable to care for the maintenance upkeep of the purely local roads by a yearly general tax levy, this is the most difficult part of the program from a practical standpoint. In the richer well settled states, it is not probably an excessive burden but for the poorer districts, it is likely that some help from some other source will be necessary. In such districts, it is likely that it will be necessary to get along for some time with comparatively unsatisfactory conditions on the purely local roads.

The essential fairness of the road tax depends on a proper equalization of value on the assessment roll and a well thought out graduated vehicle

[1] Cost of maintenance and renewal per vehicle mile is given on page 393.

tax. It is desirable to avoid rapid fluctuations in the tax rate. This can be accomplished in the matter of vehicle licenses and gasoline tax by gradually increasing them from year to year as the improved roads grow in scope and service (see page 52). It can be accomplished in the matter of general tax levy for construction by adopting a reasonable term of years for the construction program and issuing the serial bonds only as fast as actually needed for raising construction funds. (See pages 49–57.)

In order to apply the foregoing principle of taxation definitely to any specific road program, it is necessary to determine the point in any policy of progressive road improvement where the roads have reached the limit properly chargeable to general taxation and beyond which limit further improvement is a strict traffic charge. This occurs when the general road system serves the majority of the individual users for ordinary business and local pleasure purposes and when further improvement is for the added convenience of specially heavy commercial trucking on secondary roads or for the extreme convenience of pleasure traffic. To arrive at any reasonable definite conclusion, the general character and range of normal traffic must be considered. (See page 28 for the formulated conclusion.)

Traffic Requirements.—The shift in general mode of transportation from horse to motor is about completed. Horse traffic will not entirely disappear but it is not a large factor in determining road policy in many localities. There are today (1923) approximately 13,000,000 motor vehicles in the U. S. of which approximately 1,500,000 are trucks from ¾- to 7-ton capacity.

Motor traffic can be divided into three general classes:

1. The passenger car.
2. Light trucks and passenger bus lines.
3. Heavy commercial hauling trucks.

1. The light passenger car represents the largest part of the volume of road traffic, probably at least 85 per cent. This type of traffic desires all the year round roads which can be travelled at high speed with comfort, safety and convenience. This kind of traffic does not require extreme strength of pavements as the vehicles are light in weight but it does require a fairly good surface comparatively free from dust.

2. The second class of traffic, namely, light trucks up to 2½-ton capacity and passenger bus lines, desire about the same general service as the light passenger cars except that the item of extreme comfort is not as important. They require somewhat stronger pavements to handle their loads the year round but this requirement is not at all excessive and can be easily obtained on all the roads of a general utility system without too much cost. Truck traffic of this nature constitutes approximately 10 per cent of total road traffic today (1923) and represents the class of hauling equipment preferred by the individual engaged in farming, small town business, parcel delivery and general utility hauling. Available informa-

tion indicates that for the usual business man, farmer and the parcel delivery of even large corporations, the light ¾- to 2½-ton trucks with pneumatic tire equipment to at least the 1-ton size and probably to the 2-ton size will be the most popular type for hauling. This is due to reasonable first cost for the truck, moderate upkeep, high speed, comfort and general utility.

Passenger cars, these light trucks and what small amount of horse traffic still remains, constitute at least 90 to 95 per cent of the total number of vehicles using the roads; if the needs of these two classes of traffic are satisfied, the problem of giving quite complete service to the community at large is practically solved. *We can probably afford to build all the roads to satisfy 95 per cent of the users without any restrictions in regard to load or reasonable speeds which would annoy the individual in the selection of his car or truck. This can be done with moderate priced general utility roads.*

3. The class of vehicle that gives trouble is the heavy commercial truck which aggregates probably not over 5 per cent of the total rural road vehicles although for special roads they may run as high as 50 per cent of the total volume. They require extremely strong high-priced rigid pavements. The use of such trucks for moderately long hauls in competition with rail shipments is undoubtedly of considerable value to the community at large. How much it is worth and how much consideration should be given to this type in deciding on a general road policy is open to argument. It is quite generally conceded that the heavy truck seems to be the logical and popular means of intercity transportation of certain commercial products for moderately long hauls in competition with rail shipment, say 100 miles but by reason of their greater cost per mile of operation, they are not suited to make a large number of individual deliveries in successful competition with the small truck; they are, however, usefully employed for certain industries on collective routes, running on certain well defined hauling arteries with definite stops at which the local shipments are picked up; for the purpose of collecting milk for instance, certain main line roads through the heart of the producing district with collection stations at the crossroads will serve the purpose satisfactorily and economically. It is probable that if provision is made for strong pavements on the main natural commercial routes which aggregate not over 1 to 10 per cent of total road mileage depending on the general character of the district, that the community will derive about all the benefit possible from this class of hauling.

A general utility system of highways consisting of a small mileage of heavy truck roads and a large mileage suitable for passenger cars and light trucks seems to offer the most return on an investment in highways, as it in effect gives the community about all of the advantages that it can derive from the system without unjustifiably large expenditure. Such a system can be

properly constructed by general taxation but if the secondary roads are increased in cost for the benefit of heavy trucking this added cost is not properly a general community charge and such additional cost should be paid by a traffic tax.

Regulation of Heavy Traffic.—If the unregulated use of 5- to $7\frac{1}{2}$- or 10-ton trucks over *all the highways is permitted at all seasons of the year,* a slight reduction in total hauling cost might result but it would increase the first cost and maintenance of a general system out of all proportion to the added benefit in reduced hauling cost. (For the effect of different

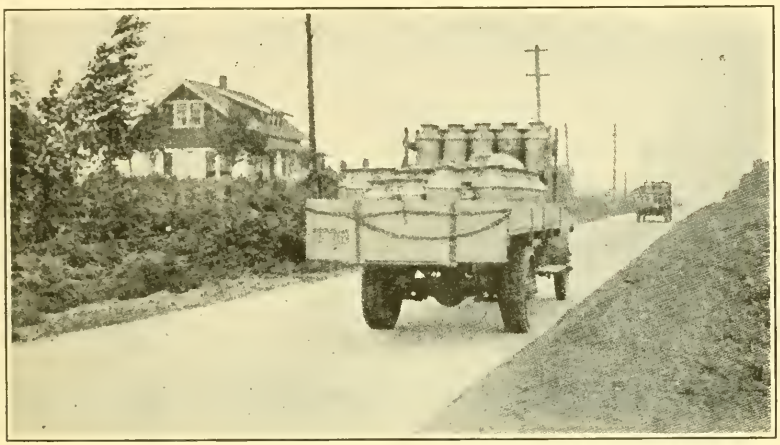


FIG. 7.—Milk collection (main road).

maximum loads on construction cost see Chap. II, page 137.) *It is evident that in order to get anywhere with a general system of roads within a reasonable term of years some restriction must be placed on heavy truck hauling.* These restrictions should not be made any more severe than necessary but reasonable restrictions in regard to load, speed and range of travel are recognized as necessary. Restrictions on load and speed have already been accomplished but restriction on range of travel has not yet been generally accomplished.

Present restrictions on improved roads do not usually permit over a 28,000 lb. gross weight (including weight of truck) and a wheel pressure not exceeding 800 lb. per inch width of tire (see Chap. II, page 77); existing statutes tend to limit solid tire trucks speed to from 12 to 15 miles per hour. It is probably desirable to go a step further and limit the use of heavy trucks to specified hauling routes, and to limit the use of even the 5-ton truck to special hauling routes except in the dry season of the year. Statutory restrictions of this nature have been adopted in some of the states and a temporary reduction in gross loading during the spring is quite common procedure but is often not well enforced.

Volume of Traffic.—Volume of traffic as it affects the administrative problem is considered by the question whether the growth in volume shall be handled by attempting to concentrate it on a few roads or by distribution over parallel routes. The answer to this appears to be that the distribution of traffic is usually the proper solution. This principle of traffic distribution seems sound for if a specified volume of traffic is distributed by the use of two roads of moderate width and cost in place of one road of exceptional width and exceptional cost, more territory is reached directly; congestion and danger are reduced and alternate routes are

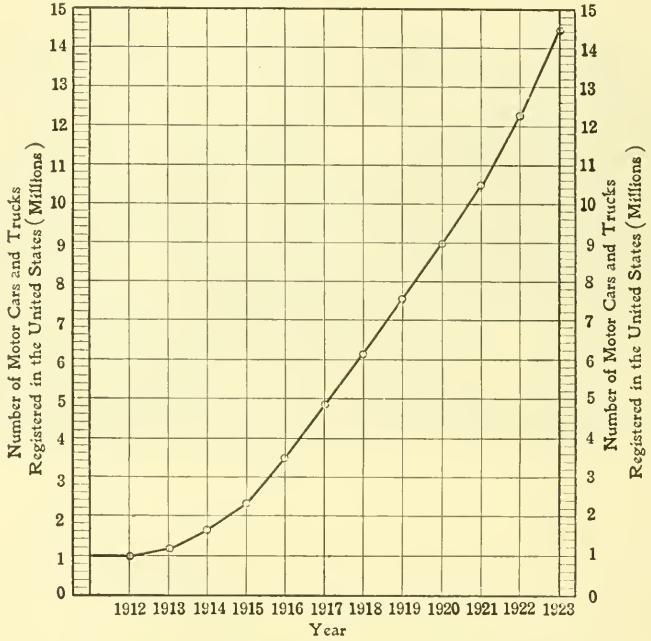


FIG. 8.—Growth of motor registration.

provided during repair periods. The normal growth in the number of improved roads tends to take care of normal traffic growth. That is, at the present stage of highway improvements, it is not likely that we are justified in building a pavement width of more than 18 to 20 ft. on single roads; it is probably better to parallel the road rather than increase the pavement widths, except for short distances near large cities where an unavoidable concentration of traffic occurs.

Traffic volume fluctuates and gradually increases. Before a road system is completed, there is no definite information on which to base probable future traffic but it can be approximated fairly closely by a careful study of the district in comparison with other similar districts in which a road system has been completed. Total motor vehicle registration gives some basis for estimating probable volume on the main roads

as while it is not a sure index of the volume of rural travel, it is a very good index of probable volume (see Figs. 8 and 8*A*) although after a certain number of motors per capita is reached the volume of travel on rural roads is not greatly affected except on holidays. During the past 4 years the registration in New York State shows a large increase but our traffic counts show only a small average increase.

Average daily traffic volume on rural roads is not so excessive as commonly believed by the city dweller who bases his opinion on holiday

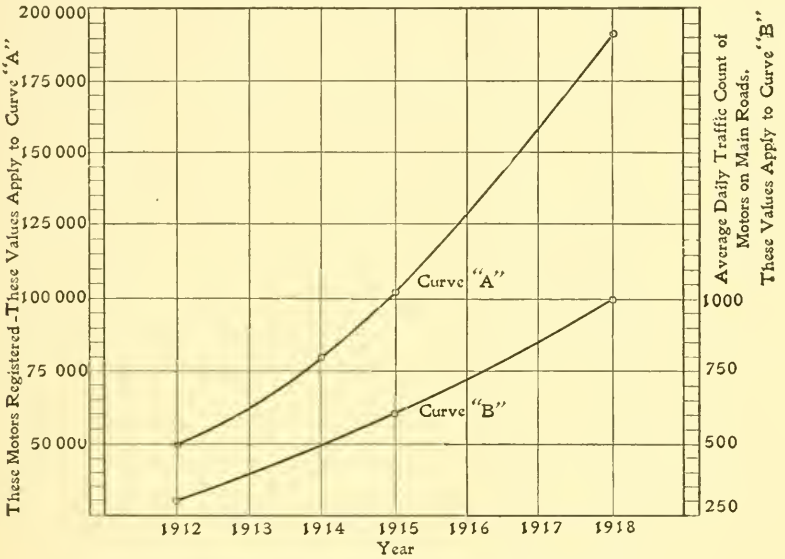


FIG. 8*A*.—Comparison of total registration with average daily motor traffic on the main roads of Massachusetts.

volume nor is it likely to continue to increase as rapidly as much of the automobile propaganda would make us think. The growth of motor vehicle traffic on rural highways has been rapid in the past few years but it cannot be expected to continue at the same rate much longer for we are rapidly approaching a reasonable limit of the number of cars which are likely to be operated for any extended mileage on rural highways (see Table 5); normal growth can be expected but at a greatly reduced rate. To illustrate the comparatively small mileage of highways carrying a large volume of traffic, the following traffic map of Western New York is inserted. At the present time not over 2 per cent of the total rural road mileage of this state carries an average of over 1,500 vehicles per day (year round average) and it is not likely that we need figure on more than 3 to 5 per cent being subjected to a higher volume than 1,500 daily average during this generation.

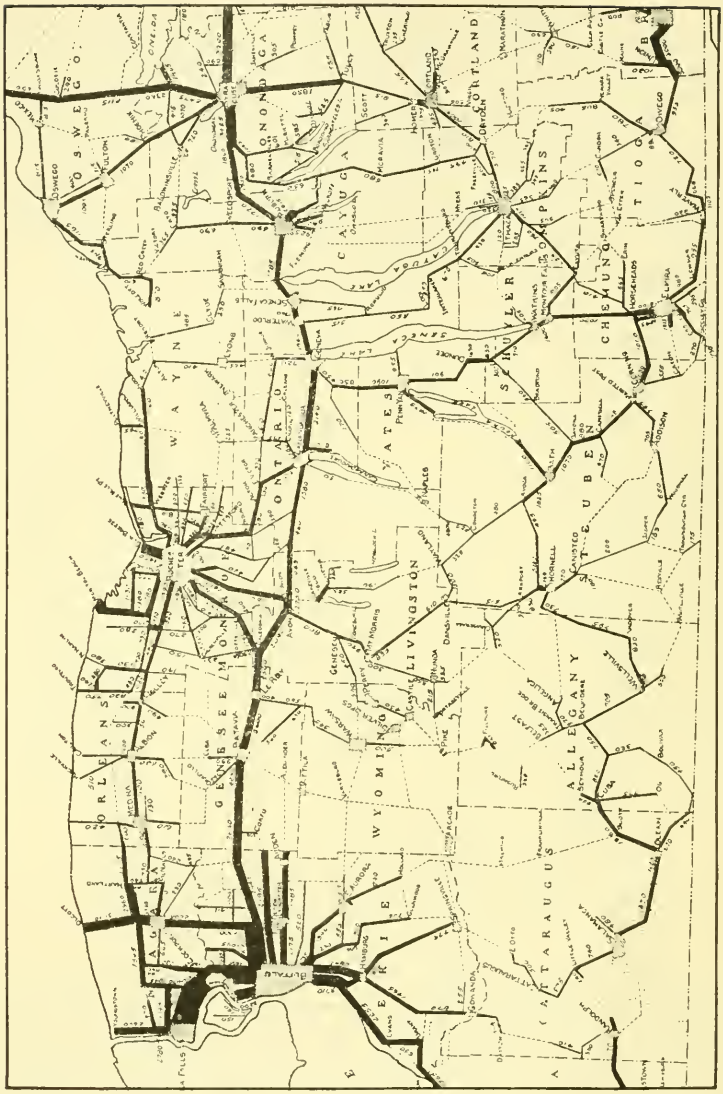


FIG. 9.—Traffic volume map. Western N. Y. (1920).

TABLE 5.—NUMBER OF PERSONS PER CAR

Rank	State	Population[1]	Cars and trucks[3]	Motor vehicles per 1,000 population	Number of persons per motor vehicle
1	California	3,805,153	931,610	244.8	4.0
2	Iowa	2,468,643	517,228	209.5	4.8
3	District of Columbia[2]	437,571	82,982	189.6	5.1
4	Kansas	1,797,489	331,936	184.7	5.4
5	South Dakota	655,532	120,031	183.1	5.5
6	Nebraska	1,333,922	244,000	182.9	5.5
7	Colorado[4]	990,320	167,562	169.2	5.9
8	Nevada[2]	77,407	12,766	164.9	6.1
9	Wyoming	211,864	34,753	164.0	6.1
10	Oregon	823,270	133,995	162.7	6.1
11	Minnesota	2,499,396	405,225	162.1	6.1
12	Indiana	3,013,134	482,678	150.1	6.2
13	Ohio	6,117,122	975,000	159.4	6.3
14	Michigan	3,977,821	624,590	157.0	6.4
15	Washington	1,433,998	224,567	156.6	6.4
16	Wisconsin	2,739,574	418,546	152 4	6.5
17	North Dakota	672,041	99,000	147.3	6.8
18	Florida	1,046,287	135,893	129.8	7.6
19	Vermont[2]	352,428	44,613	126.7	7.9
20	Illinois	6,790,524	833,920	122.8	8.1
21	Maine	777,259	94,061	121.0	8.3
22	Missouri	3,443,971	412,337	119.7	8.3
23	New Hampshire	447,592	52,343	117.1	8.5
24	Texas	4,939,630	571,981	115.8	8.6
25	Massachusetts	4,027,545	460,798	114.1	8.7
26	Delaware	230,460	26,300	114.1	8.8
27	Idaho	470,179	53,367	113.5	8.8
28	Utah	476,812	54,001	113.2	8.8
29	Oklahoma	2,162,079	240,000	111.0	9.0
30	Arizona	380,960	40,778	107.0	9.3
31	New Jersey	3,378,963	360,597	106.6	9.4
32	Montana	611,199	63,960	104.6	9.5
33	Maryland[4]	1,505,295	157,346	104.5	9 6
34	Rhode Island	626,672	65,207	104.0	9.6
35	Connecticut	1,476,483	150,913	102.2	9.8
36	Penn sy vania	9,160,326	922,062	101.3	9.9
37	New York	10,843,661	991,883	91.4	10.9
38	West Virginia	1,551,156	126,531	81.6	12.3
39	North Carolina	2,686,325	209,400	77.9	12.8
40	Virginia	2,398,441	185,076	77.1	12.9
41	Kentucky	2,462,317	175,000	71.1	14.1
42	New Mexico	372,265	24,614	66.1	15.1
43	Tennessee	2,393,077	145,000	60.5	16.5
44	Louisiana	1,849,746	110,000	59.4	16.8
45	South Carolina	1,744,408	103,049	59.1	16.9
46	Arkansas	1,816,287	97,929	53.9	18.5
47	Georgia	2,999,196	148,000	49.4	20.2
48	Mississippi[2]	1,790,618	85,645	47.8	20.9
49	Alabama	2,423,912	98,992	40.8	24.5
	Totals	110,663,502	13,048,128		
	Averages	.....	.....	11.79	8.48

[1] Population figures are estimated for July 1, 1923. The National Bureau of Economic Research's estimate is 111,023,000.

[2] No increase estimated.

[3] Vehicles from State registrations, July 1, 1923.

[4] Registrations for 5 months.

This indicates that extreme pavement width or the extensive use of very high grade pavements on a large mileage of road have not much foundation in economic necessity. The effect of a conclusion of this nature is discussed in more detail under "Classification" pages 38 to 42.

Range of Traffic.—Available data indicate that probably 90 to 95 per cent of road traffic can be classed as local service. That is, it has its origin and finish within a comparatively short distance, say 20 to 30 miles, and consists of hauling garden truck to cities, produce to shipping points, ordinary business intercourse and short pleasure trips. The other 10 per cent may be classed as long distance traffic consisting of pleasure touring, commercial travelers' cars and trucking between cities. These ratios of general traffic do not, of course, apply to any one road and may be actually reversed on certain special touring roads but they probably apply to road systems as a whole for most counties and states and indicate the general administrative principle that *Local Traffic is entitled to first consideration in the location of roads and their design, except for a comparatively small mileage of special service highways.*

The statistics compiled by the National Automobile Chamber of Commerce for 1920 show that 30 per cent of all automobiles and trucks are owned by farmers; that 60 per cent of all motors are registered from towns of 5,000 inhabitants or less and the rural districts. This is a very conservative basis for deriving the minimum volume of traffic originating on or using side roads. The general city public and even engineers are inclined to think too much of the main roads in connection with any State or National program of highway improvement. This is natural as the main roads are more spectacular; they probably carry 90 per cent of the traffic *during some part of the journey.* A system of improved main roads gives quite complete service to intercity travel; it gives quite complete service to tourist travel but it gives only partial service to local travel and local traffic is a very large proportion of the total travel on our roads. A large percentage of traffic either originates on or uses a side road during some part of its journey. That is, the main roads only provide direct contact service to about 10 to 20 per cent of the producing area of the district and this element of direct contact is a fundamental service of roads. It is therefore extremely poor policy to overemphasize the importance of the main roads to the extent of disregarding a reasonable treatment of the secondary roads. Main roads are entitled to first consideration and better construction than the local roads but they are not entitled to needlessly expensive construction which tends to delay too long a reasonable treatment of the system as a whole. The general character of the system must progress as rapidly as possible up to the standard of general utility; beyond that standard there is no harm in concentrating exceptional expenditures on special roads. The difference in volume of traffic on the local and main roads calls for a wide variation

in suitable pavement design. The administrative problem considers the general suitability of pavement types under different classes and volume of traffic.

General Suitability of Types.—It is not necessary to go into the details of the minor advantages of various standard pavements; these will be discussed under the general principles of Engineering Selection, Chap. II. Administrative action, however, properly considers the fundamental desirability of general types, their relative cost (both initial and final) and their natural rate of depreciation as far as they affect methods of taxation, terms of bond issues and maximum tax rates.

There are two general classes of pavement considered suitable for modern highways, Rigid and Flexible. The distinctive feature of the Rigid type is a non-elastic concrete base which distributes the concentrated traffic wheel loads over a safe area of the natural subsoil by slab action. All sorts of surfacings are used (sheet asphalt, brick, stone block, asphalt block or exceptionally strong concrete). The distinctive feature of the flexible type is a base course constructed of some form of macadam, gravel, fieldstone or telford, distributing the wheel loads over a safe area of the natural subsoil by means of the depth of the course and the mechanical interlocking or friction of the integral fragments of the material. This type has all sorts of surfacings, the most common surface being some form of modern macadam, but under certain conditions it is proper to use sheet asphalt or similar surfacings and almost any type of block provided the joint filler is flexible to permit slight settlement without rupture. Rigid pavements are desirable for heavy traffic. The flexible pavements are desirable for moderate and light traffic.

The advantages and disadvantages are as follows: Rigid pavements are destroyed by the action of the elements as well as by traffic. They crack due to the settlement of new fills or frost heave; they shatter due to changes in temperature; they are harsh for horse traffic. They are comparatively difficult to repair and prohibitive in cost except for rich communities. They, however, handle heavy auto trucking more satisfactorily than macadam construction. They need comparatively little surface maintenance for the first few years and for this reason traffic is inconvenienced less than on macadams; they last a longer period without reconstruction than macadam pavements and traffic is therefore interrupted less; they bridge over small areas of weakness in the subgrade such as culvert backfills, etc., better than macadams. There is no question but that they are desirable on roads carrying a large amount of heavy truck traffic.

For moderate traffic requirements however, the flexible type of pavement is probably more suitable. It complies better with the usual conditions. It generally costs less to construct, is not seriously damaged

by settlement of new grading or frost heave; can be easily and cheaply repaired; can be strengthened gradually by the addition of stone to meet practically any loading and when a solid foundation has been accomplished, can be recapped with a higher grade surface which rids it of the continuous maintenance drawback.

It is well to bear in mind that the quality of rigidity is not inherently desirable considering the fact that the earth foundation is always susceptible to heave and settlement and that this will occur to some extent no matter what precautions are taken. Rigid design should be resorted to only when the desired result can be accomplished more cheaply by this

FIG. 10.—Asphaltic concrete resurfacing on old firm macadam base.

means than by the flexible form of construction; this occurs under exceptionally heavy unit traffic. The fact that rigid pavements in general include a higher type of surfacing than macadam constructions leaves the impression in the popular mind that such a surface is the result of rigidity while as a matter of fact we have enough data to state with reasonable assurance that unless the pavement is subjected to an unusually large volume of heavy unit motor trucks, a first class macadam, fieldstone or telford base is often superior to concrete for asphalt or small block surfacings on account of the reduction in frequency of temperature cracks.

The present rather extreme tendency to favor rigid construction under moderate traffic is based largely on the record of failures of old thin inadequately designed and maintained macadam roads. Very few of the more recent, carefully designed macadams have been unsatisfactory under a traffic of less than 2,000 vehicles daily. A small percentage of all types of pavement fails either on account of poor design, poor construction

or poor maintenance but there is no such thing as type failure if moderately good judgment is used in the design and maintenance. *Road failures are personal human failures.*

Considering that road improvements are generally handicapped by a shortage of funds; that of necessity they must advance by successive stages; that the flexible types are usually the cheapest in first cost: that they are also economical in the long run for a moderate volume of traffic and that the surface maintenance problem can be minimized by using various types of surface, it is generally good policy to give these types the preference for the first stages of improvement programs;

FIG. 11.—Small 2¼-in. vitrified brick cubes on macadam base.

even for the final stages they are the best investment for the community for probably 90 to 95 per cent of the total road mileage in most districts.

To illustrate this more definitely, the following extract is quoted from the report on the Monroe County System (New York State):

"We advocate the original construction of crossroads of thick modern water-bound macadam utilizing local materials as much as possible and maintained by surface oiling.

"We advocate the original construction of our secondary radial roads, of penetration, bituminous macadam, utilizing local materials to their fullest reasonable extent and maintained by surface oiling.

"We advocate the construction of our main trunk line heavy hauling roads of rigid pavements, using the best materials that can be obtained, but varying the type to secure, in each case, the cheapest first cost pavement, always considering the possible use of local materials proper for the type of road in question. For these roads we have no choice between cement concrete, brick, sheet asphalt, asphalt block or stone block on concrete bases.

"We advocate the gradual resurfacing of the heavier traffic macadam roads with Topeka mix, small brick cubes, etc. We have successfully utilized this method in reducing high surface maintenance costs where the macadam foundation was solid enough for the traffic, and have adopted this method for a number of our roads. We have examples which have stood a 10 years' test successfully.

"We believe that the community has been better served by constructing 10 miles of macadam in place of a possible 6 miles of rigid pavement.

"We believe that the county has been better served in the past and will be best served in the future by variable road designs using for the majority of the mileage modern macadam for the original construction, later modified, if necessary, for a very limited mileage by recapping with a lower maintenance cost surface. We advocate rigid pavements eventually for approximately 10 per cent of the total mileage of our roads and for approximately 35 per cent of our State System."

Classification of Roads.—In order to strengthen the general discussion, it is, perhaps, just as well to indicate a little more definitely at this

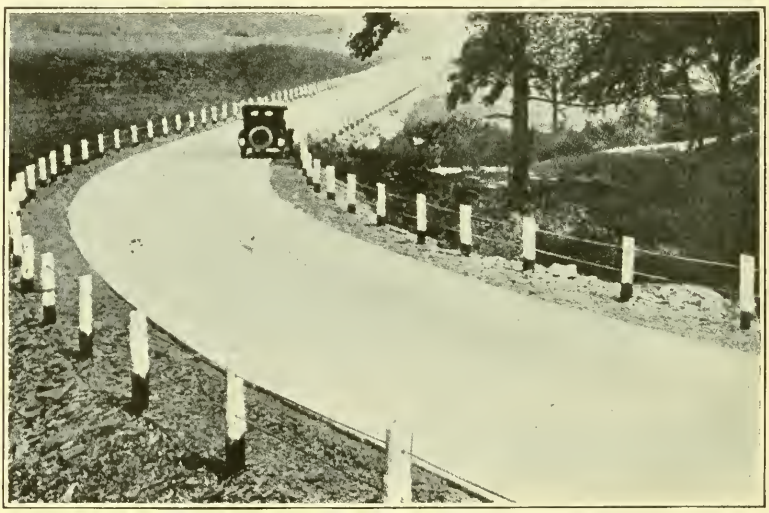


FIG. 12.—Class I road—rigid pavement. Note the sharp curve which is poor practice on a high-class road in ordinary topography.

point the initial and final cost of roads under different classes of traffic and what types of pavement appear to be best suited for different volumes of travel.

Four general classes of highway can be considered:

Class I.—These roads are usually located along natural transportation routes between large cities located at intervals of less than 100 miles. They may also occur as main radial roads out of cities of say 50,000 and upwards for distances of 5 to 40 miles or as special industrial roads or village streets carrying the concentrated traffic of a large area. These roads generally constitute from 0 to 10 per cent of the total road mileage

of the district. They usually carry 2,000 or more vehicles per day (10-hour count in summer). They should have pavements designed to support the traffic of the heaviest commercial trucks permitted by law and should have a pavement width of at least 18 ft. and preferably 20 ft.

The types most suitable and economical in the long run from the standpoint of even general utility are any Standard Brick or Bituminous Concrete surface on cement concrete bases, or Reinforced Cement Concrete Pavements. Such roads cost today (1920) for the original construction including grading, drainage, pavements and incidentals from $40,000 to $70,000 per mile. The yearly burden to the community considering interest on first cost investment plus yearly maintenance plus the yearly allowance for renewing pavement when wornout amounts to 7 to 10 per cent of the first cost of the road.[1] It seems reasonable for the community at large to assume the burden of original construction plus interest on first cost, and for vehicles to assume the burden of yearly maintenance and the renewal of wornout pavement. The actual yearly maintenance and renewal charge for these roads is at first small and gradually increases, eventually reaching 3 to 5 per cent of the first cost of the improvement and from there on stays practically constant. This is due to the fact that new pavements require a comparatively small yearly maintenance which gradually increases until their renewal is necessary. The cost of renewal is high and when any system of highways becomes old enough (15 to 25 years for this class of road), there will be a constant yearly renewal charge plus a constant yearly maintenance charge which may easily amount to $2,000 to $2,500 per mile per year average (1920 scale of costs) for this class of road.

Class II Roads.—These roads are usually main automobile routes at greater distances from the cities than Class I. They have a large touring car traffic, medium heavy farm traffic and some heavy trucking. A Class II road generally carries from 800 to 2,000 vehicles per day (10-hour count in summer). They constitute approximately 0 to 20 per cent of the total road mileage depending on the general character of the district. They should be designed to handle such traffic and require a pavement width of 15 to 18 ft.

The type of pavement generally most economical for these roads, considering final cost and immediate traffic service, is thick modern bituminous macadam, or if the volume of traffic is close to the 2,000 limit it is possible that reinforced cement concrete may be desirable under advantageous conditions of material supply.

Such roads cost today (1920) from $25,000 to $40,000 per mile to construct and the total yearly burden amounts to about $\frac{1}{10}$ of the original cost of construction.

[1] See Chap. IV.

The yearly maintenance and renewal charge for such roads will eventually (in 10 to 15 years) amount to approximately $1,500 to

FIG. 13.—Class II road construction bituminous macadam pavement. Note the shallow ditch which adds to the safety of the travel.

$2,000 per mile (1920 scale of costs). For this class of roads, this is properly a direct traffic charge.

FIG. 14.—Class III road—waterbound macadam (oiled). Note the shallow ditch which adds to the safety of traffic.

Class III Roads.—These roads are usually secondary feeder or cross-roads in well settled districts or main roads in sparsely settled districts. They generally carry 300 to 800 vehicles daily (10-hour count in

summer). They constitute 5 to 30 per cent of the total mileage. They may well be designed to handle at least a 2½-ton truck for all the year service and permit the use of 5-ton trucks in the dry season. They require a pavement width of 12 to 16 ft. The types of pavement generally most suitable for general utility are thick modern waterbound macadam with a surface application of oil, gravel oiled, or, if the travel approximates the 800 limit, the bituminous macadam type can be considered.

The roads cost from $10,000 to $25,000 per mile to construct and the total yearly burden approximates 1/10 of the original cost. The yearly maintenance and renewal charge may amount eventually in 8 to 15 years to approximately $1,000 to $1,500 per mile per year (1920 scale of costs). For this class of road it is proper to charge this directly to traffic.

FIG. 15.—Class IV narrow waterbound macadam road using local materials. Note the shallow ditch which adds to the safety of traffic.

Class IV Roads.—These roads constitute the purely local service roads carrying a volume of less than 300 vehicles daily. They constitute 70 to 95 per cent of the total road mileage. They may well be designed for the all year round use of 2½-ton trucks. They do not require much refinement in grading design or in the width of hard surface. A width of 8 to 12 ft. is sufficient.

The most suitable type is gravel or waterbound macadam. Earth or sand clay can be used as a temporary makeshift but in northern climates they can only be considered as temporary expedients as any type of surface not usable the year round for at least 2½-ton trucks is not a general utility road.

Class IV Roads cost $2,500 to $10,000 per mile (1920) and the total yearly burden is about 1/10 of the original cost of construction. For this class of road, it is probable that the community at large should assume the entire burden of construction, interest, maintenance and renewal which means eventually for the items of maintenance and renewal alone about $300 per mile per year (1920 scale of costs); this figure is reached gradually and becomes a fairly stable burden in 5 to 10 years after the roads are constructed.

Importance of Maintenance.—Effective maintenance is the best possible road investment the community can make. It increases the life and lowers the final cost of the improved roads. It decreases the cost of traffic operation and increases the comfort of travel. It speeds up the general effectiveness of a road system that is being gradually improved by construction or reconstruction. This last is the keynote policy for the poorer districts and is of vital importance to a large part of the county at present (see Table 7, page 48). For the poorer districts traffic service can be bettered at once, first, *by systematic maintenance* of all the existing roads; this does not solve the problem by any means but it keeps it from getting worse; second, by the immediate construction of a large mileage of gravel or similar constructions on secondary roads suitable for moderate loads (up to 2½-ton truck and eliminating the large truck for year round use) and giving these roads *systematic maintenance.* This solves the problem up to the standards of general utility traffic for agricultural districts. It does not solve the heavy traffic problem, but it helps and is better than waiting indefinitely for the completion of a system of boulevards. Third, the construction of thick modern macadam *systematically maintained* for the main roads and strong expensive rigid pavements *systematically maintained* for the main commercial hauling routes aggregating a comparatively small percentage of the total mileage. These roads meet heavy travel requirements.

Fairly good immediate service for traffic is only possible by means of Effective Maintenance. It is both physically and financially impossible to solve the problem of improvement of traffic conditions over a large mileage solely by immediate Reconstruction of the Roads. Maintenance is not entirely eliminated no matter what type of road is built. Fairly efficient maintenance has been accomplished in many cases and is poor in others but the fact that it can be achieved provided enough attention is contrated on it means that it is possible to get somewhere with a serviceable road program in a reasonable time.

To illustrate the result of a lack of a temporary service program, we will cite New York State. This state has been improving its main roads by State and County aid for 20 to 25 years; the system is still incomplete in many cases. New York's construction program has been excellent; its maintenance of the roads after improvement has been fairly

good for some years past but very little has been done to better the condition of the existing roads at gaps in the improvement. That is, for the past 10 or 15 years, short gaps and detours in stretches of modern roads have caused needless inconvenience to the traveling public. Under the New York road program, the State does not assume direct responsibility for the condition of the roads on the proposed system until they have been improved by state construction. As soon as a road is adopted as part of the system, the town in which it is located loses all interest in it and does nothing to keep it in condition although supposed to keep it in shape until it is improved by the state. These gaps do not require large expenditures but the conditions can at present be very materially bettered

FIG. 16.—Earth road near Cochrane, Wisconsin. A gap in the main road system not yet reached by the construction program. Kept in serviceable shape for traffic by patrol maintenance.

by comparatively small expenditures on temporary repair and maintenance. All travelers curse these gaps and are more than willing to have their license fee raised slightly to eliminate temporarily the worst features of such roads. It is probable that an extra charge between $1 and $2 per vehicle license per year applied to such work under direct state supervision would result in a tremendous improvement of the few gaps remaining in this particular state (1921).

Order of Construction.—A reasonable order of construction is difficult to work out from a practical standpoint as it is subject to the most insistent kind of political pressure. Each community demands first attention. Broadly speaking, a proper order of construction considers the principle of giving the most service as soon as possible. If all the roads are in poor shape, the first improvements may well start from

shipping points, cities, villages, etc. (any center of activity), gradually extending the system of improvements until they connect as a complete system. If part of the old roads are fairly serviceable, the worst sections should be improved to provide fairly good immediate service. In any case, business roads should be given the preference over purely scenic routes for long distance pleasure touring until a network of economically serviceable roads have been completed.

Raising Funds for Construction.—Construction funds for extensive programs are usually raised by Serial or Sinking fund bonds. The "Pay as you go" yearly appropriation policy is sometimes used for small programs as it is the cheapest in final cost but for an extensive program

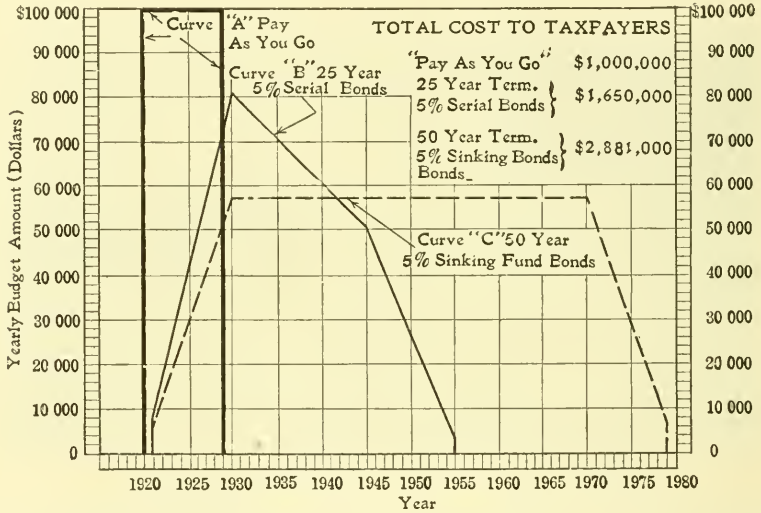

Curve "A" Pay As You Go
TOTAL COST TO TAXPAYERS
Curve "B" 25 Year 5% Serial Bonds
"Pay As You Go" $1,000,000
25 Year Term. 5% Serial Bonds $1,650,000
50 Year Term. 5% Sinking Bonds Bonds $2,881,000
Curve "C" 50 Year 5% Sinking Fund Bonds
Yearly Budget Amount (Dollars)
$100 000
90 000
80 000
70 000
60 000
50 000
40 000
30 000
20 000
10 000
0
1920 1925 1930 1935 1940 1945 1950 1955 1960 1965 1970 1975 1980
Year

FIG. 17.—Comparative total and yearly costs for a $1,000,000 10-year construction program financed in different ways. (Construction period 1919 to 1929.)

the bond method is to be preferred as it permits more rapid construction, makes it possible to develop a more stable engineering organization, reduces rapid fluctuation of tax rates and throws a fair share of the burden on to the future. For comparison of total and yearly cost, see Fig. 17.

Serial bonds are in more favor than the sinking fund method as the history of public sinking fund bonds is not encouraging; the necessary yearly appropriations are often neglected and the sinking fund not well administered. This was discussed in considerable detail in Appendix A of the first volume of this series.

Bond Terms.—A reasonable term of bond depends on the rate of depreciation of the road improvement and on the maximum tax rate the community can afford.

An examination of Fig. 18 shows that the yearly budget charge for retiring bond issues does not lessen much for a bond term of more than 30 years. Considering the fact that the total cost of bond financing increases with the length of the term (see Table 6) and that the yearly charge does not decrease much for the longer terms, it is evidently desirable not to exceed the 25- or 30-year term. The 25-year serial bond method of raising funds for original improvement of highways seems to meet the requirements of the usual situation for the following reasons:

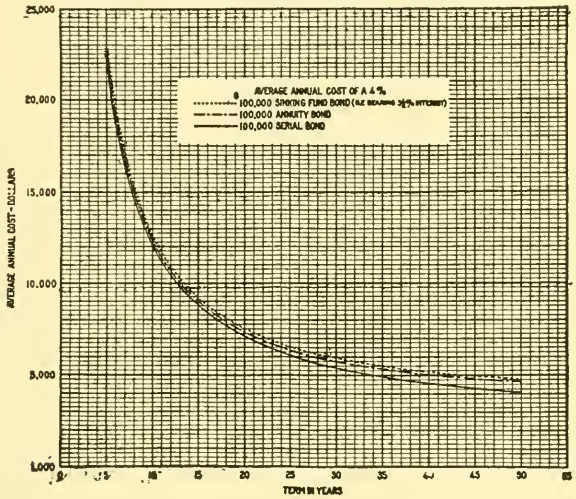


FIG. 18.—Graph showing effect of length of bond term on average annual tax budget. (Little advantage is gained by lengthening the term beyond 25 years.)

TABLE 6.—TOTAL COST OF SINKING FUND BOND

Total cost of a $100,000 sinking fund bond bearing 3, 4, 5 or 6 per cent interest, with sinking fund drawing 3½, and maturing at different periods from 5 to 50 years

Term in years	3 per cent	4 per cent	5 per cent	6 per cent
5	$108,241	$113,241	$118,241	$123,241
10	115,241	125,241	135,241	145,241
15	122,738	137,738	152,738	167,738
20	130,722	150,722	170,722	190,722
25	139,185	164,185	189,185	214,185
30	148,114	178,114	208,114	238,114
35	157,494	192,494	227,494	262,494
40	167,309	207,309	247,309	287,309
45	177,540	222,540	267,540	312,540
50	188,169	238,169	288,169	338,169

TOTAL COST OF SERIAL BOND

Total cost of a $100,000 serial bond bearing 3, 4, 5 or 6 per cent interest and maturing at different periods from 5 to 50 years

Term in years	3 per cent	4 per cent	5 per cent	6 per cent
5	$109,000	$112,000	$115,000	$118,000
10	116,500	122,000	127,500	133,000
15	124,000	132,000	140,000	148,000
20	131,500	142,000	152,500	163,000
25	139,000	152,000	165,000	178,000
30	146,500	162,000	177,500	193,000
35	154,000	172,000	190,000	208,000
40	161,500	182,000	202,500	223,000
45	169,000	192,000	215,000	238,000
50	176,500	202,000	227,500	253,000

The rate of depreciation of the different general kinds of modern highways is approximately as follows, assuming that the maintenance is moderately good and that the pavements are well designed and used under a volume of traffic for which they are suited.

Road improvements include grading, drainage, pavement foundation, pavement surface course and incidentals. The first three items are practically permanent. The surface and incidentals require renewals at quite regular intervals. Double track macadam surfaces cost about 40 per cent of the total cost of original improvement and generally last about 10 years before renewal is necessary. That is, for this class of improvement it is fairly safe to figure on a natural depreciation of 40 per cent of the original investment in say 10 years after which very little further depreciation occurs as the balance of the work retains its value quite indefinitely if properly maintained. For rigid pavements, the surface course needs renewing in about 15 years as a rule and this item amounts to about 40 to 60 per cent of the cost of original improvement. That is, the depreciation is about 40 to 60 per cent in 15 years. For any general system of highway improvements composed of macadams and rigid pavements, *a bond term which results in paying off* 40 *per cent of the principal and interest in* 10 *years and* 60 *per cent in* 15 *years is probably sound financing; the* 25*-year (or less) term bond complies with this condition.*

For reconstruction of surfaces and yearly maintenance the "Pay as you go" method financed by direct vehicle taxation for the main highways and by direct general tax levy for the purely local roads seems reasonable. If bonds are used for a reconstruction program to renew the pavement surfaces the bond term should probably not exceed 15 years but this method is hardly warranted except in unusual cases.

Maximum Tax Rates.—Maximum highway tax rates are strictly a local problem; they depend on the relative need for highways considering the entire public work program; the general character of the district, the prevailing rates, etc. A rapid fluctuation of rate is undesirable. General tax rates at present (1921) for highway purposes range from $\frac{1}{10}$ to 5 mills. This, of course, does not mean much unless the ratio of assessed to real value is known and also all sorts of other factors. It is not likely that it is desirable to exceed 3 to 4 mills in many cases for such work where the assessed valuation is moderately high.

GASOLINE TAX (1922)

STATE	TAX PER GAL., CENTS
Alabama	2
Arizona	1
Arkansas	3
Colorado	2
Connecticut	1
Delaware	1
Florida	1
Georgia	1
Idaho	2
Indiana	2
Kentucky	1
Louisiana	1
Maine	1
Maryland	1
Mississippi	1
Montana	2
Nevada	2
New Mexico	1
North Carolina	3
North Dakota	$\frac{1}{2}$ to 1
Oklahoma	1
Oregon	2
Pennsylvania	1
South Carolina	2
South Dakota	2
Texas	1
Tennessee	2
Utah	$2\frac{1}{2}$
Vermont	1
Virginia	2
Washington	1
Wyoming	1

Gasoline taxes range from 1 to 3 cents per gallon; vehicle license taxation averages today (1921) about $8 per year per motor vehicle. It is certain that the sum total raised by licenses and gasoline tax methods will have to be gradually increased as the highway systems are completed and give more service. 1922 rates are generally less than half that required for a reasonable distribution of the tax burden. Eventually an average tax

per car per year of from $25 to $50 may be required. It is not desirable for such vehicle taxes to exceed an amount which in effect means a charge over one cent per ton mile actually travelled on the highways as this is a fair estimate of the direct saving in operating cost of the improvements to traffic.[1]

TABLE 7

State	Population	Assessed valuation 1920	Motor vehicles, 1920	Total mileage of roads	Population per mile of rural road	Assessed value per mile of road	Motor vehicles per mile of road
Alabama	2,138,000	$ 670,178,000	58,898	55,446	39	12,100	1.1
Arizona	204,300	836,000,000	28,979	12,075	17	69,200	2.4
Arkansas	1,574,400	359,436,307	49,448	50,743	31	7,100	1.0
California	2,377,500	3,806,815,179	493,463	61,039	39	62,400	8.1
Colorado	799,000	1,099,993,673	104,366	39,780	20	27,600	2.5
Connecticut	1,114,700	1,114,008,294	105,600	14,061	79	79,300	7.5
Delaware	202,300	.....	16,152	3,674	55	.....	4.4
Florida	921,600	233,750,566	56,253	17,995	51	13,000	3.1
Georgia	2,609,100	569,394,457	126,563	80,669	43	70,500	1.6
Idaho	325,600	430,863,703	41,780	24,396	13	17,700	1.7
Illinois	5,638,600	1,790,182,292	478,438	95,647	56	18,500	5.0
Indiana	2,700,900	1,390,165,973	227,255	73,347	37	19,000	3.1
Iowa	2,224,800	1,417,289,249	363,000	104,074	21	13,600	2.1
Kansas	1,672,500	2,084,411,876	228,601	111,052	15	18,780	2.0
Kentucky	2,289,900	887,045,799	90,008	57,916	40	15,300	1.6
Louisiana	1,656,400	1,452,582,291	50,000	24,563	67	59,500	2.0
Maine	742,400	351,910,817	53,424	23,537	31	14,900	2.3
Maryland	1,295,300	950,000,000	98,995	16,459	79	57,700	6.0
Massachusetts	3,366,400	3,885,495,341	288,059	18,681	180	207,800	15.4
Michigan	2,810,000	3,325,943,828	325,813	74,190	38	44,800	4.4
Minnesota	2,075,700	1,481,355,657	259,743	93,517	22	15,700	3.2
Mississippi	1,797,100	.....	45,030	45,779	39	.....	1.0
Missouri	3,293,300	1,918,977,855	244,427	96,041	34	20,000	2.6
Montana	376,000	1,277,097,843	59,312	39,204	9	32,600	1.5
Nebraska	1,192,200	355,759,828	200,100	80,272	15	4,430	2.5
Nevada	81,900	2,000,000,000	9,305	12,182	7	16,400	0.8
New Hampshire	430,600	453,327,679	30,008	14,020	31	32,300	2.2
New Jersey	2,537,200	2,744,168,603	189,167	14,817	171	18,500	12.8
New Mexico	327,300	155,086,964	20,000	11,873	28	13,100	1.7
New York	9,113,600	12,230,166,984	555,789	79,398	115	154,000	7.0
North Carolina	2,206,300	421,421,410	109,000	50,758	43	8,300	2.1
North Dakota	577,100	265,315,957	82,886	68,796	8	3,700	1.2
Ohio	4,767,100	5,424,872,985	516,225	86,354	55	68,000	6
Oklahoma	1,657,200	1,439,581,118	151,300	107,916	16	13,400	1.4
Oregon	672,700	588,194,399	83,332	36,819	18	16,000	2.3
Pennsylvania	7,665,100	6,141,384,210	490,337	91,555	84	67,400	5.3
Rhode Island	542,600	510,915,710	39,563	2,170	280	23,500	1.8
South Carolina	1,515,400	208,348,279	70,143	42,226	36	4,900	1.1
South Dakota	583,900	1,172,709,171	104,625	96,306	6	12,200	1.1
Tennessee	2,184,800	.....	80,422	46,050	46	.....	1.7
Texas	3,896,500	.....	329,700	128,960	32	.....	2.6
Utah	373,351	199,630,625	35,144	8,810	42	20,200	4.0
Vermont	356,000	173,380,861	26,807	14,249	25	21,200	1.2
Virginia	2,061,600	676,880,567	95,000	53,388	31	12,700	1.8
Washington	1,142,000	718,065,597	168,146	42,428	27	16,900	3.9
West Virginia	1,221,100	1,366,139,828	50,203	32,024	38	42,000	1.6
Wisconsin	2,333,900	2,929,281,764	236,974	75,707	31	38,700	3.1
Wyoming	146,000	113,198,396	21,371	14,797	10	76,500	1.
			7,668,094	2,445,760			

[1] See page 393 for maintenance costs per vehicle mile.

Example of Classification of Roads and Program Finance Estimates.—The actual layout and classification of highways along the lines discussed make any administrative policy definite. Figure 1 (Frontispiece) illustrates a definite administrative analysis for a system of main highways. The district shown is used for this discussion as it is typical of the usual problem; it serves a range of conditions from a poor county to a rich county. The map is explained as follows and the district analyzed to illustrate the application of the administrative considerations discussed in this chapter. An analysis of this character gives a fairly rational basis for a general scheme and while it is not possible to forcast costs exactly it is useful in determining the scope of the program and the general means of meeting the yearly costs.

The classification shown (Frontispiece) was made by the author as the result of a careful analysis of this district. It is not an official classification but represents closely the engineering judgment of a number of the local engineers for the main road system included in the State Aid Layout approved or proposed in 1920.

The roads shown in red are Class I requiring rigid pavement construction at a probable construction expenditure (1921 cost conditions) of approximately $50,000 per mile for an economic pavement type and general satisfaction of traffic. They will probably eventually require $2,000 to $2,500 per mile per year for maintenance and renewal.

The roads shown in green are Class IIA requiring either rigid pavements or high class surfaces on macadam bases with a probable construction expenditure (1921) of approximately $40,000 per mile and eventually a maintenance and renewal yearly charge of approximately $2,000 per mile (1921 scale of costs).

The roads shown in black are Class II requiring modern macadam pavements at a construction cost (1921) of approximately $30,000 per mile and eventually a maintenance and renewal yearly charge of approximately $1,500 per mile (1921 scale of costs).

The roads shown in yellow are Class III requiring a construction expenditure of about $20,000 per mile and a maintenance and renewal charge of approximately $1,000 per mile per year (1921 scale of costs).

The single line roads are Class IV town roads requiring macadam or gravel construction at a cost of $2,500 to $10,000 per mile (1921) for satisfactory all year round service and will need a maintenance and renewal yearly expenditure of from $150 to $500 per mile (1921 scale of costs).

This classification is a strict engineering classification based on final economy considering construction cost, maintenance and renewal. It is necessary to estimate how much such a system will probably cost to construct and maintain and then see if the district can support it and what modifications may be necessary to give the most service.

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TABLE 8.—APPROXIMATE COST OF SYSTEM

Class of road	Number of miles	Total cost of construction[1]	Eventual total, yearly maintenance and renewal[1]
Class I	170	$ 8,500,000	$ 425,000
Class IIA	140	5,600,000	280,000
Class II	600	18,000,000	900,000
Class III	440	8,800,000	440,000
Total state county system	1,350	40,900,000	2,045,000
Class IV (town roads local service)	5,350	27,000,000	1,350,000
Grand total	6,700	$68,000,000	$3,400,000

[1] Estimated at prices prevailing in 1921.

This district started its modern system in an energetic way about 1905. Assume that a 25-year construction program on the main state roads was considered reasonable and an indefinite period on the town roads doing something each year and completing it as rapidly as possible; that it is intended to carry out the general principles of taxation, etc., previously discussed; that competent tax experts and economists have analyzed the situation in regard to probable increases in assessed valuation and construction costs for the period adopted and that their conclusions agreed fairly closely with the resources of this district in 1920 (15 years after the program started). These resources are as follows:

RESOURCES OF DISTRICT, 1920

County	Assessed valuation	Total number motor vehicles	Total fees (motor)
Genesee	$ 40,000,000	5,000	$ 48,000
Livingston	24,000,000	5,000	48,000
Monroe[1]	350,000,000	34,500	372,000
Ontario	53,000,000	6,700	67,000
Orleans	30,000,000	3,700	36,000
Wyoming	26,000,000	2,800	27,000
Total	$523,000,000	57,700	$598,000[2]

[1] Monroe County contains the City of Rochester, assessed valuation $280,000,000. Total rural valuation district $240,000,000.

[2] Average fee per car $10. Assessed valuation per mile of road $80,000. Nine motor vehicles per mile of road.

By comparison with Table 7, it can be seen that this district is above most states in financial strength for highway purposes and that if caution must be exercised in this case it is certainly important to avoid excessive expenditures in districts poorer than this example. The analysis is based on the following plan of financing:

Finance construction of Class I and IIA roads by general tax levy over entire district.

Finance construction of Classes II and III by general tax 50 per cent and county tax 50 per cent.

Finance Class IV construction by general tax 25 per cent and county tax 75 per cent.

Maintain and renew Classes I, II and III by vehicle license fees and gasoline tax.

Maintain and renew Class IV by general tax 25 per cent and county tax 75 per cent.

Reasonable assumptions seem to be that an average general rural tax of 3 mills can be used with a maximum of 6 mills; that an average highway tax applied to rural roads of 1½ mills and a 3-mill maximum can be levied in the cities.

That the assessed valuation in 1930 will be 30 per cent higher than shown in 1920. That there will be 30 per cent more motors at the time the maintenance charge reaches its peak.

These are, we believe, conservative assumptions on valuation and rather high on tax rates.

Consider first, the maintenance and renewal of the main roads by vehicle taxation for if it is not possible to maintain and renew the roads after they are built, it is useless to construct them.

Maintenance and Renewal.—Table 8, page 50, shows the estimated maintenance and renewal for the future completed system of Class I to III roads (1,370 miles) as $2,000,000 annually chargeable to vehicle taxes. We may expect this to be borne by not less than 70,000 cars or an average fee of approximately $25 to $30 per car. The present average fee is $10. No gasoline tax is used in this district. This indicates that a gradual increase will be necessary. As a matter of fact in this district, there are at present 750 miles of state road completed and under maintenance; the estimate for maintenance and renewals for this completed mileage was $1,200,000 for 1921; the legislative allotment was $750,000, an entirely inadequate sum; the motor license fees from this district were $600,000, an entirely inadequate sum. The experience in this district backs up the figures given and indicates an immediate necessity for a raise in auto fees; this is the first general point brought out by the analysis. Unless vehicle fees or some other form of traffic tax are increased to a supporting basis, the method of financing is not sound.

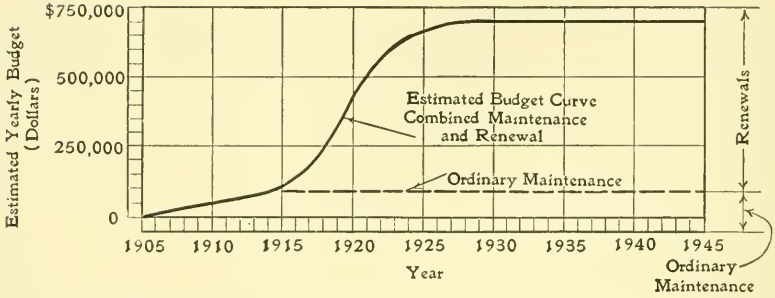


FIG. 19*A*.—Estimated yearly combined maintenance and renewal budget (1921 costs conditions).

Class I and II*A* roads (310 miles).
Assumed construction period 1905 to 1915
Assumed life of pavement surface 12 to 15 years.
Note how the curve steepens up when pavement renewals becomes necessary and then flattens out to a high level line when the entire system is old enough for the renewal charge to become constant.

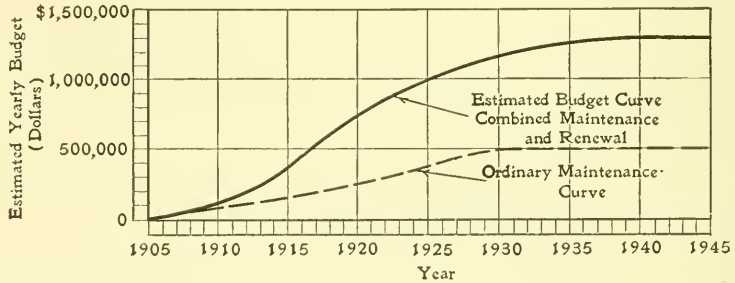


FIG. 19*B*.—Estimated yearly combined maintenance and renewal budget (1921 cost conditions.)

Class II and III roads (1,040 miles).
Assumed construction period 1905 to 1930.
Assumed life of pavement surface 8 to 12 years.

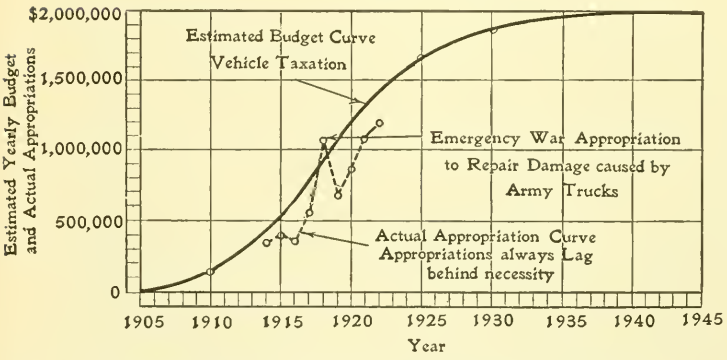

$2,000,000
1,500,000
1,000,000
500,000
0
Estimated Yearly Budget and Actual Appropriations
Estimated Budget Curve Vehicle Taxation
Emergency War Appropriation to Repair Damage caused by Army Trucks
Actual Appropriation Curve Appropriations always Lag behind necessity
1905 1910 1915 1920 1925 1930 1935 1940 1945
Year

FIG. 19*C*.—This figure combines 19*A* and 19*B* and includes Classes I, 2*A*, II and III roads.

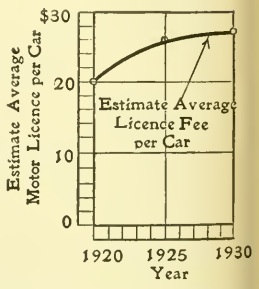
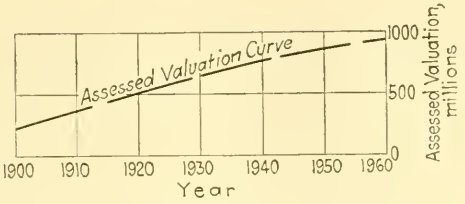


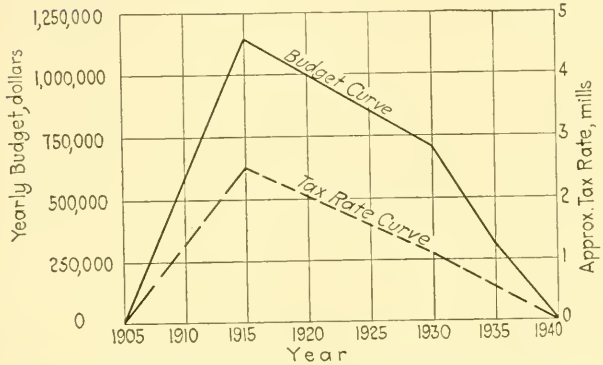
FIG. 19*D*.—Estimated necessary auto license fee.

FIG. 19.—Diagrams representing estimated combined maintenance and renewal yearly appropriations for the district shown in frontispiece.

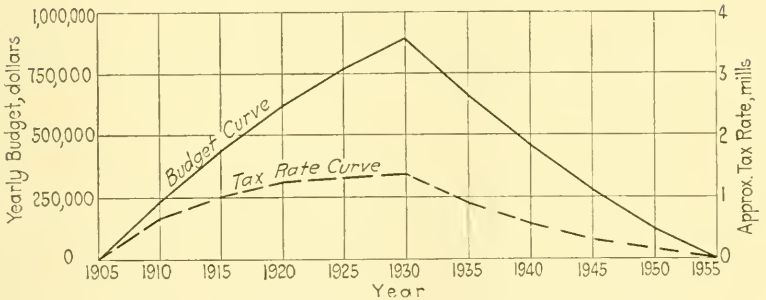
NOTE.—These appropriations should be raised of vehicle taxation. This data complied in 1920 by W. G. Harger in connection with a personal study of this district under assumed conditions to illustrate the value of classification in connection with a general finance plan. This same method can be applied to any program at any stage of procedure provided the data is carefully worked out considering the age and type of existing pavements.



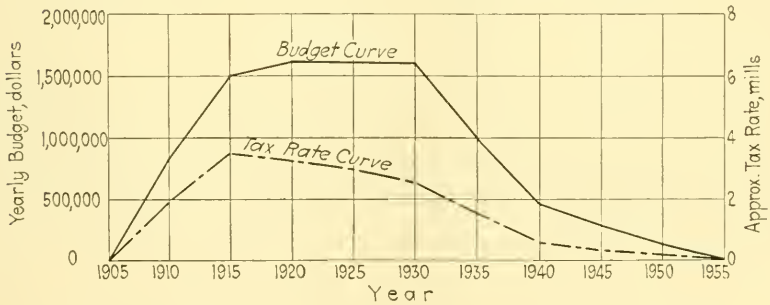
Estimated Assessed Valuation. Division 7



Tax Curve for Construction Class I and II*A* Roads. Division 7



Tax Curve for Construction Class II and III Roads. Division 7



Tax Curve Class I, II*A*, II and III Roads. Construction Program

FIG. 20.

NOTE.—See pages 55 and 59 for tabulation of budget.

Construction Class I and IIA Roads.—Consider the construction of Class I and IIA roads by general tax over the entire district. The construction cost of these roads Table 8, page 50, is estimated at $14,000,000. Assuming that they are financed by 25-year 5 per cent serial bonds on a 10-year construction program beginning in 1905 the maximum tax rate in 1915 would be approximately 2 mills over the entire district (see Fig. 20).

These roads are of primary benefit and considering that their rapid construction up to excellent standards will not require a tax rate above 2 mills maximum (⅔ of the maximum city rate permissible) it seems good sense for this district to concentrate effort on these roads and get them into service.

Construction Class II and III Roads.—The general city and general rural tax rate is affected as follows for the construction of Class II and III Roads. Assume a 25-year construction period as reasonable.

The estimated construction cost Table 8, page 50, is approximately $27,000,000 half of which is to be paid for by general tax over the entire district. Figure 20 shows the general tax rate for Classes I and IIA, for Classes II and III and the last graph for all Classes I, IIA, II and III. The maximum general tax rate runs about constant under this illustrative program from 1915 to 1930 and amounts to about 3 mills which is about the limit of allowable taxation under the assumptions used. That is, from 1915 to 1930, we have about reached the limit of city taxation for rural highway purposes and cannot give much aid to local town roads (Class IV) unless the mileage of Class II and III roads is reduced and put into Class IV.

Consider the total tax rate for Wyoming County (a poor district). In addition to the general tax of 3 mills for Classes I, IIA, II and III Roads, the county must pay for 50 per cent of the Class II and III roads within its boundaries. The county's share of the construction cost of these roads is estimated at approximately $1,000,000. The total highway tax rate for Wyoming County for Class I, IIA, II and III roads is illustrated in Fig. 21 and shows the limit of highway expenditure is nearly reached from 1915 to 1935 without doing much for the local town roads (Class IV).

The consideration of both the city and rural tax rates in this district for Class I, IIA, II and III roads indicates the second general conclusion, namely, that caution must be exercised not to throw too much mileage into Class II and III roads as it tends to delay somewhat the mileage and immediate construction of local roads, which can be fairly well served under Class IV rating.

CLASS I AND IIA ROADS—TABULATION OF FIG. 20 (page 53)

Year	Bonds issued to date	Outstanding indebtedness	Annual charges		
			Interest	Repayment account	Budget for year
1905	$ 1,400,000	$ 1,400,000	$ 0	$ 0	$ 0
1906	2,800,000	2,744,000	70,000	56,000	126,000
1907	4,200,000	4,032,000	137,200	112,000	249,200
1908	5,600,000	5,264,000	201,600	168,000	369,600
1909	7,000,000	6,440,000	263,200	224,000	487,200
1910	8,400,000	7,560,000	322,000	280,000	602,000
1911	9,800,000	8,624,000	378,000	336,000	714,000
1912	11,200,000	9,632,000	431,200	392,000	823,200
1913	12,600,000	10,584,000	481,600	448,000	929,600
1914	14,000,000	11,480,000	529,200	504,000	1,033,200
1915	.....	10,920,000	574,000	560,000	1,134,000
1916	.....	10,360,000	546,000	560,000	1,106,000
1917	.....	9,800,000	518,000	560,000	1,078,000
1918	.....	9,240,000	490,000	560,000	1,050,000
1919	.....	8,680,000	462,000	560,000	1,022,000
1920	.....	8,120,000	434,000	560,000	994,000
1921	.....	7,560,000	406,000	560,000	966,000
1922	.....	7,000,000	378,000	560,000	938,000
1923	.....	6,440,000	350,000	560,000	910,000
1924	.....	5,880,000	322,000	560,000	882,000
1925	.....	5,320,000	294,000	560,000	854,000
1926	.....	4,760,000	266,000	560,000	826,000
1927	.....	4,200,000	238,000	560,000	798,000
1928	.....	3,640,000	210,000	560,000	770,000
1929	.....	3,080,000	182,000	560,000	742,000
1930	.....	2,520,000	154,000	560,000	714,000
1931	.....	2,016,000	126,000	504,000	630,000
1932	.....	1,568,000	100,800	448,000	548,800
1933	.....	1,176,000	78,400	392,000	470,400
1934	.....	840,000	58,800	336,000	394,800
1935	.....	560,000	42,000	280,000	322,000
1936	.....	336,000	28,000	224,000	252,000
1937	.....	168,000	16,800	168,000	184,800
1938	.....	52,000	2,600	112,000	114,600
1939	.....	0	0	56,000	56,000
1940	.....	0	0	0	0
			$9,091,400	$14,000,000	$23,091,400

NOTE.—This tabulation refers to Fig. 20, page 53.

As a matter of fact, the State-County System for the entire district shown in the Frontispiece (Div. 7) was reduced in mileage in 1921 from 1,370 proposed miles to 1,100 adopted miles, as the former appeared to be too ambitious a mileage for extremely high cost roads and was apparently delaying a more liberal policy of State Aid in connection with the Class IV roads. Even the 1,100 mile program is rather high.

Class IV Roads.—Considering local Class IV roads as a separate problem, the main difficulty will be in maintaining and renewing them by general tax levy after they are once built. Consider the problem from the standpoint of maintenance and renewal and work back from this to justifiable construction cost.

Suppose we put off modern construction of the local roads (Class IV) until 1935 and make the best of them with minor repairs and patrol maintenance. How are we going to handle them in Wyoming County at a later date when the main road debt is practically cancelled? Assume that the assessed valuation of Wyoming County rises to $35,000,000 and

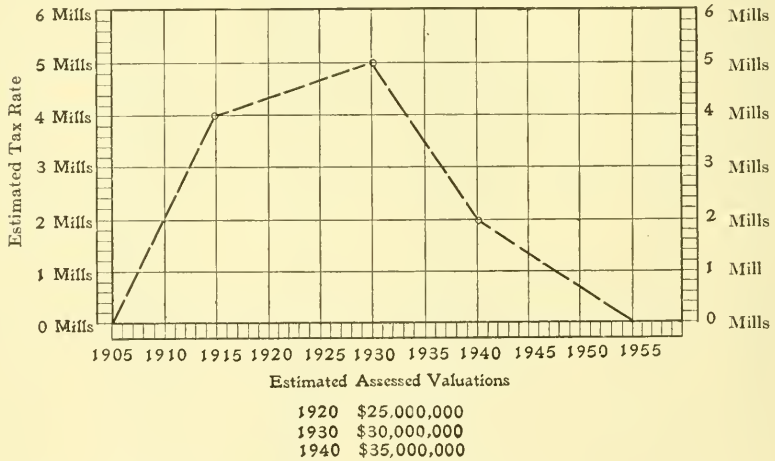


Fig. 21.—Diagram of estimated tax rate for Wyoming County including its share of the general tax for Class I, IIA, II and III roads and the local tax for 50 per cent of Class II and III roads.

that beginning in 1940 it is reasonable to raise $130,000 annually to cover 75 per cent of the cost of construction, maintenance and renewal of these roads, the other 25 per cent being outside aid.

Wyoming County has approximately 900 miles of Town Roads. Probably it can not afford to spend on maintenance and renewal per year over $100 per mile which with reasonable outside aid amounts to not over $150 per mile per year. This warrants an average construction expenditure of not over $3,000 per mile for such roads, which means that even for a considerable time in the future they can probably achieve only

moderately light construction for most of the Class IV roads, and that it is extremely important to keep heavy trucks off the purely local roads if they are ever to get any reasonably good general system.

The meaning of this rather rough analysis of a very typical district seems to be that care must be exercised to eliminate needless expenditure even on the main roads and most certainly this is true of the Class II, III and IV roads. We have had numerous cases in the past few years of plans calling for the expenditure of $40,000 to $50,000 per mile on unimportant roads carrying not over 300 to 500 vehicles a day and it is against this tendency that we wish to throw the weight of the evidence as strongly as possible. Any department even in a rich state which advocates excessive expenditure of this kind endangers the success of even its own road programs. There are cases where counties have hesitated to take advantage of outside aid as they figured that they could construct locally a road that would serve the purpose for less than their share of an extremely expensive Standard State Road. This illustrates the folly of unbalanced design. It may seem to the reader that the point is overemphasized, but to the writer nothing seems more likely to discredit highway engineers than needless expenditures of this kind or the lack of a firm policy in favor of traffic regulation on local roads.

Research and Records.—The main hope for improvement in highway design lies in scientific research coordinated with actual service tests by systematic records. Too much emphasis cannot be placed on the value of Research as a factor in highway programs but its use is in some cases more or less preverted. Research has a decided advertising value to the executive and a decided physical design value to the engineer. From the standpoint of the executive, the main value of research is to help create public confidence in the administration. Judicious publicity along the line of advertising that an earnest effort is being made to utilize scientific knowledge is considered desirable. This is a valid use but care should be taken that the reasonable recommendations resulting from scientific investigation are actually utilized in design and construction and not merely shelved after the advertising value has been extracted. There is no defense for the use of research merely as part of the garment of respectability. From the standpoint of the constructing engineer, research is valuable in establishing definite basic laws. Exact comformity with scientific recommendations however may well proceed cautiously. It is necessary for the student to bear in mind that the finer shading of laboratory conclusions in regard to construction methods or experimental analysis of minor variations in vehicle operation costs as affected by different types of surfaces of essentially the same general class of pavement are relatively unimportant factors in design or type selection as compared with the necessities of the situation in terms of limited funds, demand for immediate service, popular approval of certain types,

unavoidable construction imperfections which always occur, etc. That is, if funds are limited, we cannot very well put off needed construction by telling the taxpayer that experiment has determined that an auto tire will last 12,243 miles on a new rigid pavement which is in perfect condition and which is free from ice and snow and 11,339 miles on macadam and that considering final operation cost of his Ford car during the summer we are going to wait 5 years till we can get money enough to build an expensive road by his house.

In connection with construction, research has developed many useful basic laws one example being a rational theory of concrete mixtures. This theory has improved general practice but this or any other theory cannot be carried too far in design because every once in a while a laborer forgets to put in a sack of cement or the water valve leaks or the inspector goes to sleep and allowances must be made for such contingencies.

Systematic engineering records and costs have rarely received the attention to which they are entitled and much of the accumulated experience of the past has been lost on this account. One fundamental difficulty of our system of highway organization is the rapidly changing executive personnel and there is not much incentive to pass on personal knowledge when the men anticipate removal for purely political reasons. *For this reason, standard practice is lagging way behind individual knowledge.* Records become increasingly important as reconstruction programs are inaugurated. For such work we personally know of many cases where lack of knowledge of the exact conditions has resulted in needlessly expensive reconstruction designs or in inadequate provision for the repair of short lengths of weak pavements.

Research and well kept permanent records are essential parts of any permanent highway program but they are merely aids to a reasonable solution.

Organization Personnel.—The success of a highway program really depends more on the individual character and professional ability of the men making up the organization than on any other feature; if the men are high grade, nothing radically wrong is likely to develop and the designs are usually economical. If the men are inexperienced or second rate, no system of standardization or rigid red tape procedure will prevent wasteful design and poor construction work. It is difficult to retain high grade men in the public service as usually the salaries are niggardly and the advancement slow and often not based on personal ability. One of the foremost State Highway Engineers resigned in 1920 from his position on the ground that it was impossible to develop an organization which could expend the State Highway appropriations in a really efficient manner; that the trouble lay in low pay and the difficulty of advancing the best men; that while they had succeeded in employing and training

GENERAL TAX, CLASS II AND III ROADS—TABULATION OF FIG. 20 (page 53)

	Bonds issued to date	Outstanding indebtedness	Annual charges		Budget for year
			Interest	Repayment account	
1905	$ 540,000	$ 540,000			
1906	1,080,000	1,058,400	$ 27,000	$ 21,600	$ 48,600
1907	1,620,000	1,555,200	52,920	43,200	96,120
1908	2,160,000	2,030,400	77,760	64,800	142,560
1909	2,700,000	2,484,000	101,520	86,400	187,920
1910	3,240,000	2,916,000	124,200	108,000	232,200
1911	3,780,000	3,326,400	145,800	129,600	275,400
1912	4,320,000	3,715,200	166,320	151,200	317,520
1913	4,860,000	4,082,400	185,760	172,800	358,560
1914	5,400,000	4,428,000	204,120	194,400	398,520
1915	5,940,000	4,752,000	221,400	216,000	437,400
1916	6,480,000	5,054,400	237,600	237,600	475,200
1917	7,020,000	5,335,200	252,720	259,200	511,920
1918	7,560,000	5,594,400	266,760	280,800	547,560
1919	8,100,000	5,832,000	279,720	302,400	582,120
1920	8,640,000	6,048,000	291,600	324,000	615,600
1921	9,180,000	6,242,400	302,400	345,600	648,000
1922	9,720,000	6,415,200	312,120	367,200	679,320
1923	10,260,000	6,566,400	320,760	388,800	709,560
1924	10,800,000	6,696,000	328,320	410,400	738,720
1925	11,340,000	6,804,000	334,800	432,000	766,800
1926	11,880,000	6,890,400	340,200	453,600	793,800
1927	12,420,000	6,955,200	344,520	475,200	819,720
1928	12,960,000	6,998,400	347,760	496,800	844,560
1929	13,500,000	7,020,000	349,920	518,400	868,320
1930	.....	6,480,000	351,000	540,000	891,000
1931	.....	5,961,600	324,000	518,400	842,400
1932	.....	5,464,800	298,080	496,800	794,880
1933	.....	4,989,600	273,240	475,200	748,440
1934	.....	4,536,000	249,480	453,600	703,080
1935	.....	4,104,000	226,800	432,000	658,800
1936	.....	3,693,600	205,200	410,400	615,600
1937	.....	3,304,800	184,680	388,800	573,480
1938	.....	2,937,600	165,240	367,200	532,440
1939	.....	2,592,000	146,880	345,600	492,480
1940	.....	2,268,000	129,600	324,000	453,600
1941	.....	1,965,600	113,400	302,400	415,800
1942	.....	1,684,800	98,280	280,800	379,080
1943	.....	1,425,600	84,240	259,200	343,440
1944	.....	1,188,000	71,280	237,600	308,880
1945	.....	972,000	59,400	216,000	275,400
1946	.....	777,600	48,600	194,400	243,000
1947	.....	664,800	38,880	172,800	211,680
1948	.....	453,600	30,240	151,200	181,440
1949	.....	324,000	22,680	129,600	152,280
1950	.....	216,000	16,200	108,000	124,200

General Tax, Class II and III Roads.—*Continued*

	Bonds issued to date	Outstanding indebtedness	Annual charges		Budget for year
			Interest	Repayment account	
1951	.....	$129,600	$ 10,800	$ 86,400	$ 97,200
1952	.....	64,800	6,480	64,800	71,280
1953	.....	21,600	3,240	43,200	46,440
1954	.....	0	1,080	21,600	22,680
1955	.....	0	0	0	0
	.....	.....	$8,775,000	$13,500,000	$22,275,000

some very excellent talent that it was impossible to hold a reasonable proportion of the men and that the turnover was high.

This action expressed in a very effective way the quite universal handicap of a highway executive. Under the existing conditions, the solution most often adopted lies in retaining a few high grade men as active subordinate assistants to politically appointed heads and rigidly standardizing detail procedure utilizing quite low pay men for the actual design and construction end of the program. Such a system produces a moderately good type of highway as can be seen by observing the results to date but any engineer actually acquainted with the working of this system will say that the cost of construction is needlessly high in most cases and that the community pays a tremendous amount of money every year because they have not sense enough to adopt a more liberal policy of salary and reward. High grade engineering pays for itself in actual construction money saving ten times over the additional salary cost but this fact is not generally recognized by the public and while road officials understand it, they either find it difficult to override public sentiment or actually prefer mediocre talent on account of the greater freedom which they have to carry out their own pet schemes. Until the entire organizations from inspectors up to the Chief are raised to a good standard of individual ability, waste is bound to occur.

Executives have said that they knew moderate priced roads well designed, constructed and maintained would serve satisfactorily but that such results were hard to obtain under existing organization conditions and that in self-defense they considered it good policy to design a rigidly standardized $40,000 a mile highway even on comparatively unimportant Class III roads to get $20,000 worth of service. This expresses in an extreme way the continual waste that is more or less the result of niggardly public service employment policy.

Nothing takes the place of the individual judgment of the rank and file men of the organization. What most organizations need are high

grade detail designers and constructors who are encouraged to use their experience and judgment and are not tied down too much by rigid standardization or their work crippled too much by demands for plans at such short notice that reasonable care and study cannot be given to each road. This must not be construed as an argument for unrelated work by a crowd of individualists but departmental heads may well rid themselves of the idea that *all* wisdom originates at the official top and that standardization will take the place of brains.

Conclusion of Chapter.—This chapter may be briefly summarized as follows:

First.—From the standpoint of economic return on road investments, it is desirable to limit the type of improvements to standards of general utility until a general system has been accomplished, particularly if the program is financed by a general tax levy.

Second.—Efficient maintenance of both the old existing roads and the new improved roads is the only possible means of giving moderately good general traffic service within a reasonable time.

Third.—It is probably desirable in most cases to begin by concentrating effort and at least 50 per cent of the total available highway expenditure on a rapid construction program for certain main roads constituting from say 5 to 15 per cent of the total road mileage. Such roads should if possible be built up to truly economic engineering standards of general utility.

Fourth.—After this is accomplished it generally seems desirable to raise the standard of the entire balance of the system as best we can. This may require low, makeshift engineering standards of pavement design for the first stages of improvement, depending entirely on the financial strength of the district. Under a reasonable tax distribution it is generally possible to improve the system gradually by successive stages up to the standards of general utility provided traffic is subjected to reasonable regulation.

Fifth.—Unrestricted traffic makes it impossible to make any progress with local service roads in the poorer districts, as the comparatively light roads that these districts are able to finance are destroyed faster than they can be built. Rigid traffic regulation on a rational basis depending on the local conditions is a more positive help in local road improvement programs than even quite generous State Aid moneys. Where it is impossible to finance roads that will economically handle heavy trucking it is obvious that the only solution requires the elimination of such units during the first stages of improvement. Even the first stages of improvement, however, should probably permit the use of 2½-ton trucks.

Sixth.—The reasonable distribution of the tax burden, and sound methods of raising construction and maintenance funds are fundamentals in the success of any program.

Seventh.—The classification of roads tends to stabilize procedure through successive administrations and tends to encourage a rational distribution of funds and well-balanced engineering type selection.

Eighth.—Sound general policy in the matter of handling growth in traffic volume apparently favors the principle of ultimately distributing traffic over moderate priced parallel routes rather than by concentration on a few extremely wide and extremely expensive highways.

Ninth.—Sound general policy in the matter of pavement type seems to usually lead to the use of flexible pavements for the earlier stages of improvement programs, gradually strengthening the foundation and improving the character of the surface up to practically any standard of convenience, except for a very small percentage of the mileage (Special Service Roads) on which from the outset there is no doubt but that the rigid type of pavement is the most economical investment.

Tenth.—The success of any program depends on the ability of the executive to develop an efficient design, construction, and maintenance organization. In highway work as in any other line the whole matter hinges on personnel and this particular phase of the problem can only be well handled under a liberal policy of public service salaries and recognition of ability.

The following chapter considers the detailed engineering analysis which governs the selection of pavement type for specific cases.

CHAPTER II

GENERAL ENGINEERING PRINCIPLES OF PAVEMENT DESIGN AND TYPE SELECTION FOR SPECIFIC ROADS

Chapter I considered the effect of limitations of expenditure on pavement type selection. The discussion in this chapter is based on the assumption that funds are available to build the most economical type of pavement from the standpoint of final cost. Theoretically, this requires comparative estimates for different pavements considering first cost, interest, maintenance, renewal and motor operation costs. The problem is not susceptible to a close theoretical analysis as there are too many variable and more or less indeterminate factors involved. There is, however, enough data based on experience with modern traffic supplemented by scientific research to make a rough analysis and arrive at reasonable conclusions.

Experienced highway engineers are able with the data now at their disposal to make successful economic pavement designs of varying depth to meet different conditions of load, soil and pavement type. These designs based on the data recorded in this chapter should save at least 10 per cent on construction cost over the usual rigidly standardized macadam design in use by many State Departments (1922) and the percentage of yearly repair due to depth weakness should not exceed $\frac{3}{10}$ of one per cent of the surface area. Rigid pavement design is open to more uncertainty but even this type can be designed with assurance of reasonable success without needless first cost.

Additional experiment and research will undoubtedly improve standard practice but pavement design will probably remain largely a matter of experience and judgment expressed empirically. The uncertainty in judging soils and future traffic, the cost of applying laboratory methods of design to the rapidly fluctuating sub-soil conditions of the ordinary road, and the personal equation in design, inspection, construction and maintenance make the rigid application of formulated theory of doubtful value. Pavement design and estimates of final cost must also consider the general standard of excellence of public work in the district involved. This standard is never theoretically perfect but it is usually higher under State and Federal control than under local control. The following general discussion is based on data collected under State administrative conditions. Details of design for each type are considered in Chap. III.

The selection of pavement type on rural highways differs from the city or village street problem. In cities, the consideration of appearance,

cleanliness, personal preference of abutting property owners and the ability to replace the surface without a material change in elevation outweigh the factor of cost. On rural highways, cost governs, provided the surfaces are moderately safe and the pavements of equal strength. No one pavement combines all the desirable qualities for either city streets or rural highways. Each standard pavement has individual advantages and disadvantages and the problem of selection lies in analyzing the requirements for the road in question and selecting the most suitable type for the particular case.

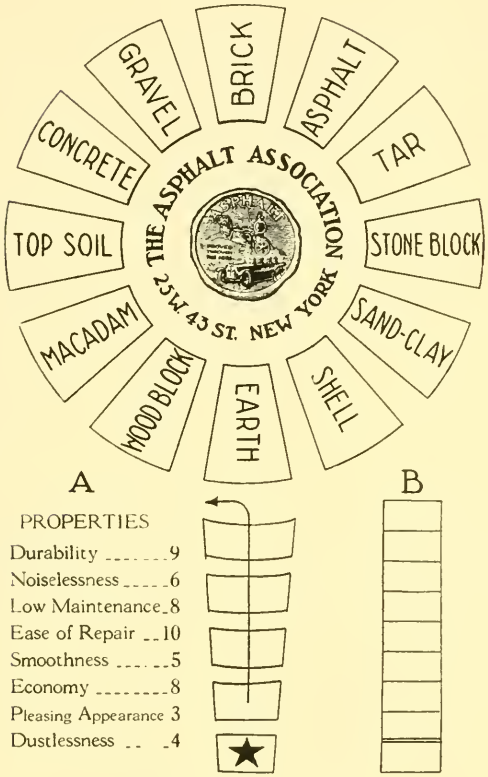
Broadly speaking, where all classes of road materials are locally available, the more expensive first cost pavements generally cost less to maintain, so that the final cost is not greatly affected by the selection of type; this conclusion however, does not apply to the extremes of traffic (gravel roads are not economical under heavy traffic nor are rigid pavements economical under light traffic) nor does it apply to special conditions of material supply where the local materials are only fit for certain types of pavement. Type selection is well worth careful attention but any effort to split hairs in determining final cost is of doubtful value. *The practical problem for any specific road is confined, first, to the determination of the various pavements suitable for the general class of traffic the road will carry, and second, to the selection of the particular pavement which will utilize to best advantage the good quality local materials or the cheapest good quality imported materials.* Special conditions such as grade limitations, appearance in villages, special flood overflow, maintenance, renewal and motor operation cost complete the analysis.

Engineering Judgment Versus Advertising Propaganda.—A well made engineering analysis of economic type selection is quite logical and convincing (see official report page 153). It is often at variance with conclusions which have been given wide publicity by the advertising efforts of the different material industries. Two examples of common advertising appeal are quoted as follows:

Figure 22 shows a recent clever advertising novelty gotten out by the Asphalt Association. If you follow the purely mechanical operations of the "Pigs in the Clover" diagram and don't make a mistake you generally stop at the advertiser's product. The same diagram could be used to advertise any product by simple arbitrary transposition of the order of Pavements. The advertisers of course make no claim that this is a sample of wisdom; it is merely a method of reminding the observer that asphalt is available for his work and that it is a good product. This general type of publicity however, has considerable effect on unthinking popular demand for certain types regardless of a reasonable economic solution.

Another material propaganda effort produced the following gem which can be made to apply to any well constructed modern pavement by

What Pavement to Select?



DIRECTIONS

1. Note in Table A those properties which you consider important and enter their corresponding numbers in column B
2. Total the oumbers in column B.
3. Next, starting with Block ★ count upward to the circle and continue counting the blocks clockwise, (to the left) around the circle until the number counted corresponds to the total of column B.
4. Call the last block counted No. 1 and proceed to count the blocks backward, (in the reverse direction) around the circle until the number counted again correspoods to the total of column B.
5. The Block at this point names The Type of Pavemeot to Select.

FIG. 22.

modifying the first verse. This is really a clever bit of advertising and we heartily approve of it as such but deprecate the misleading inference.

CEMENT ROADS

"Hordes of autos,
Now remind us
We should build
Our roads to stay
And, departing,
Leave behind us
Kinds that rain
Don't wash away."

"When our children
Pay the mortgage
Father made
To haul the load,
They'll not have to
Ask the question
Here's the bond,
But where's the road?"

If this were to be used in advertising say any kind of bituminous binder for Penetration Bituminous Macadam the first verse might be changed to read as follows. This change is made with apologies to the original unknown author.

BITUMINOUS MACADAM ROADS

"Hordes of autos
Now remind us
We should build
Our roads real well.
And, departing
Leave behind us
Kinds that frost
Don't crack to hell."

If you wish to descend to the standard of the "Sweet Singer of Michigan," Brick Surfaces might be advertised as follows:

"Hordes of autos now remind us
Cars must not skid or slip or slide.
Roads should not provide the reason
Father died and died and died."

It is more or less of a travesty on ordinary human intelligence that stuff of this kind seems to have more effect on people than a straight plain statement of facts.

Reasonable type selection and design depends on consideration of the following factors:

1. Traffic Classification.
2. Suitable Pavements based on Traffic Classification.
3. Strength of Pavements.
   (*a*) Sub-grade Soils.
   (*b*) Depths of Pavement required considering traffic, soil and type of pavement.
4. Widths of Pavement.
5. Construction Cost. (Comparative Estimate different types.)
   (*a*) Amounts of material required.
   (*b*) Materials available; amount and suitability.
   (*c*) Alternate Estimates different types, different widths.
6. Maintenance and Renewal Costs (Different types).
7. Reasonable Maximum Expenditures.
   (*a*) Based on economic travel benefit.
   (*b*) Based on intangible benefit.
8. Recommended Design.
   (*a*) Type.
   (*b*) Width.

Examples of Official Reports covering these points are given on pages 153, 159, 477 and 581.

General Suitability of Types (Based on Traffic Classification).—The general suitability of types was discussed in Chap. I, page 35. For convenience, the conclusions are repeated on page 68 in tabular form.

The first step in the reasonable selection of type is to classify the roads on the basis of probable traffic after improvement, in some such manner as outlined in Table 9. For reconstruction, this is a simple matter based on careful traffic census results. For original improvement, the most reliable basis for such a classification is a general study of the district considering the natural traffic lines, industries using road haulage, summer resorts, etc. A traffic census has a very limited value for, purposes of classification when it is applied to uncompleted road systems; this was discussed in considerable detail in the first book of the series. The classification of roads as state routes, national routes, etc., has no value whatever as far as pavement type selection is concerned as different parts of such routes are subject to a wide range in the character of traffic. An example of a traffic classification is shown in the frontispiece map which was explained in Chap. I, page 49. As each road comes up for improvement, an examination of such a map determines at a glance the general classification of the proposed road and definitely establishes what types of pavement can be considered for more detailed comparative estimates of cost. A definite example of this procedure as applied to design practice is given on pages 153 and 159.

TABLE 9.—GENERAL SUITABILITY OF TYPES

Class I roads	Class II roads	Class III roads	Class IV roads
Special service roads, 2,000 or more vehicles daily. (10-hour count in summer.)	Ordinary mixed traffic, 800 to 2,000 vehicles daily. (10-hour count in summer.)	Ordinary mixed traffic, 300 to 800 vehicles daily. (10-hour count in summer.)	Local traffic less than 300 vehicles daily. (10-hour count in summer.)
Asphalt block on concrete base. *Brick block* on concrete base. *Bituminous concrete* on concrete base. *Reinforced cement concrete.* *Stone*[3] *block* on concrete base.	*Bituminous*[1] *concretes* on old firm macadam base. *Small*[1] *block pavements* with flexible joint filler on old firm macadam base. *Reinforced cement concrete.* *Penetration bituminous macadam.*	*Bituminous macadam.* *Waterbound macadam* (oiled). *Bituminous gravel.* *Gravel* (oiled).	*Macadam* (oiled) *Gravel* (oiled) *Sand clay* in districts not subject to severe winters.
WIDTHS OF PAVEMENT[2] (IN FEET)			
18 to 20 with additional width of macadam shoulders.	15 to 18 with additional stone shoulders.	12 to 16	8 to 12

[1] The use of these types on newly built macadam is not safe practice.
[2] Extra width on sharp curves.
[3] Special conditions only.

Value of Comparative Construction Cost Estimates.—Careful comparative cost estimates have a well defined practical value if common sense is used in their application. In a great many cases these estimates are carelessly made under stress of a time limitation and sometimes they are purposely misleading in order to give an apparent advantage to certain types. For these reasons they are often considered as a joke and serve to illustrate the old saying that "Figures don't lie but liars will figure." The practical value of comparative estimates has, however, been amply proved even when handicapped by political interference. In laying out a season's program of contracts, the responsible executive can list the results of such estimates and have available for reference the roads and mileage on which it is desirable from an engineering standpoint to use macadam, concrete, asphalt, brick, etc. If for any reason the administration is more or less committed to a distribution of patronage

and desires to throw certain percentages to the various types, this distribution can be made with the least harmful violation of sound design by following as closely as practicable the listing prepared. As a matter of fact, an engineering classification of this kind is the safest basis for patronage distribution as it is defensible and results in the use of practically all available materials as different types of pavement can be used to advantage under different conditions. A policy of uniform one-type design is most certainly to be avoided as it is dangerous procedure and poor policy from all angles.

Comparative estimates of cost of different rigid pavements or different flexible pavements can be made without much difficulty but the comparison of rigid types with the flexible types in a more difficult matter. Such comparisons require designs of equal strength and the assignment of reasonable maintenance and renewal costs to the different types.

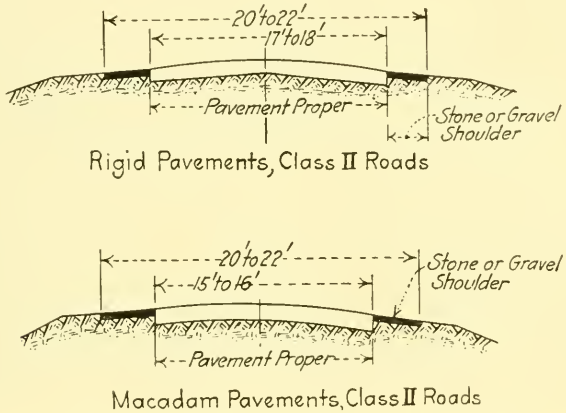


FIG. 23.—Comparative widths Class II traffic.

Probably no two engineers will agree on equal strength or the relative cost of maintenance and renewal but the range of disagreement is not extreme and average values are probably quite close to the truth. It is certainly desirable to formulate a tentative basis of comparison.

Comparative first costs depend on pavement widths, strength and unit costs.

Comparative Pavement Widths.—Where all the pavements compared are either of the rigid type or of the flexible type, the widths are the same for each pavement. Where rigid pavements are compared with the flexible type on Class I roads, the width remains the same as convenience in passing governs design. Where rigid pavements are compared with flexible macadam for the same Class II or III road, it is proper to use less width for the macadam pavement proper than for the rigid pavement

provided gravel or stone shoulders of equal out-to-out width are used (see Fig. 23). This is based on the fact that dangerous ruts are more likely to develop along the edges of rigid pavements than where macadam is used and also because the cost of maintenance is high along the dividing line where traffic continually passes from rigid to flexible support. It is desirable to keep most of the traffic on the pavement proper where the rigid type is used which makes extra width necessary.

The widths given in Table 10 are considered reasonable for comparative estimates. Extra widths used on curves are shown in Table 10A and 10B.

FIG. 24.—Typical shoulder ruts along edge of rigid pavement on heavy traffic road. This is Road 5 New York State carrying 5,000 vehicles daily (12-hour count).

TABLE 10.—COMPARATIVE WIDTHS (IN FEET)

Class of road	Rigid pavements		Macadam or gravel	
	Pavement proper	Out-to-out width armored shoulders	Pavement proper	Out-to-out width armored shoulders
Class I	18′–20′	22′–24′	18′–20′	22′–24′
Class II	17′–18′	20′–22′	15′–16′	20′–22′
Class III	16′	16′	12′–16′	16′
Class IV	.....	.....	8′–12′	.....

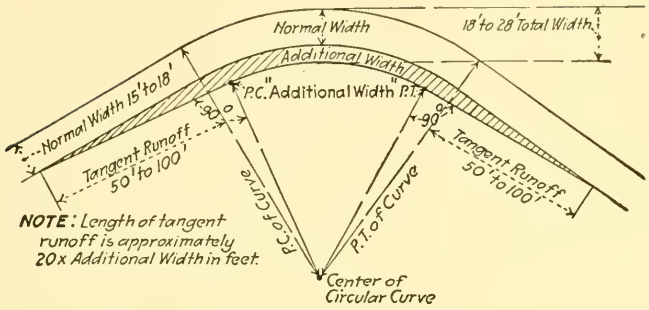

Normal Width
18' to 28' Total Width
Additional Width
Normal Width 15' to 18'
P.C. Additional Width P.T.
Tangent Runoff 50' to 100'
90°
90°
Tangent Runoff 50' to 100'
P.C. of Curve
P.T. of Curve
NOTE: Length of tangent runoff is approximately 20 x Additional Width in feet.
Center of Circular Curve

TABLE 10A.—CLASS I TRAFFIC (SHARP CURVES)

Radius of road center line in feet	Total pavement width in feet	Length tangent runoff in feet
100	25	100
150	24	90
200	23	90
300	22	80
400	22	80
500	21	70
600	21	70

NOTE.—Normal pavement widths of 18 to 20 ft. used on all curves having a radius greater than 600 ft.

TABLE 10B.—CLASS II AND III TRAFFIC (SHARP CURVES)

Radius of road center line, in feet	Total pavement width on curves for a double track road (local service) in feet	Length tangent runoff in feet
50	29	100
75	25	100
100	23	100
150	22	90
200	21	90
300	20	80
400	20	80
500	19	70
600	18	50

NOTE.—Normal pavement width (15 to 18 ft.) used on all curves having a radius greater than 600 ft.

Pavement Strength.—Pavement strength depends on the type, soils and thickness. The design of strength considers traffic loads, the supporting power of the underlying foundation soil and the manner in which the pavement transmits the load to the foundation soil. Pavement design need not provide for anything like as large a factor of safety as used for bridges or buildings for human life is not endangered by pavement failure. As a matter of fact, if a small percentage of any extended mileage of pavement does not fail, it indicates that the roads were over designed and that too much was spent to insure against minor repair.

Value and Limitations of Theoretical Design.—The observed action of roads under actual traffic tests is the most reliable basis for the determination of strength. While customary local practice affords some help in this matter, it is not in all cases entirely convincing for a number of reasons. The limitation of funds tends to keep the design of strength to a minimum and in some cases it is carried to a dangerous minimum. In localities where the modern road systems are in the first stage of construction, current practice is not always based on very extensive traffic evidence. In some districts, material propaganda has had considerable effect on state standards, and such influence is not always based on engineering requirements. It is therefore just as well to outline the problem from a theoretical standpoint and then make modifications that seem to be necessary to coordinate theory with actual road conditions.

A theoretical analysis is of distinct advantage to the student as it separates the general problem into factors, investigates each factor and then attempts to formulate the conclusions. In this way he gets a definite idea of the problem. The value of formulated theory to the practicing engineer lies in consistent designs and in providing a means whereby he has some basis of estimating the effect of proposed changes in statuatory load limitations on construction costs. It is well to bear in mind that pavement formulae are largely mathematical expressions of limited experiment coordinated by experience, and that judgment must be used in their application; the danger of a formula lies in its appearance of exactness; its successful use depends on good judgment in assigning values to the more or less indeterminate variables. For these reasons an approximate theoretical discussion has been developed followed by examples of current pavement practice which are in turn modified by recommended practice which shows the trend of design and gives rational results under actual tests of traffic.

Fundamentals of Pavement Design.—Before developing the detail discussion of the various factors in design, is it, perhaps, just as well to outline the fundamental differences between flexible pavement and rigid

pavement design; it will be noted that each type has certain well-defined advantages.

Utilization of Subgrade Support.—Macadam or flexible base pavements move in conjunction with and stay in contact with the underlying earth subgrade. If unequal settlement of the subgrade occurs, the surface becomes uneven under traffic action but continues to transmit the wheel loads directly to the underlying subgrade. These surface inequalities can be easily and cheaply repaired without destroying the effectiveness of the underlying pavement. If large areas settle the pavement follows the movement without any particular loss of effectiveness. *Macadam design is based on the principle of utilizing subgrade support at all points. The pavement thicknesses are varied to produce the maximum allowable pressure on the subgrade and in this way utilize the full supporting value of the subgrade.*

Rigid pavements do not conform to the settlement of the subgrade. They bridge over small areas where the underlying soil has settled and they fail entirely where large areas settle unevenly. *Rigid pavement design is predicated on the lack of soil support for small areas. The pavements are designed to bridge over small areas by means of their slab or beam action (as this is the main advantage of the type) but it is prohibitive in cost to apply this method of design for large areas of settlement. Rigid pavement design cannot utilize soil support to its full value.* That is, a rigid pavement strong enough to bridge over small areas of no support has a needlessly high distributing power (even on poor soils) where the pavement is in actual contact with the subgrade.

The frequency or size of the small areas of no support seem to have very little relation to the relative normal supporting power of different subgrade soils within the usual range of foundation soils. These small areas of no support are due more to non uniformity of the subgrade, warping of the slabs due to temperature, and to construction imperfections rather than to low general supporting power of the soil. Some increase in rigid pavement strength is desirable on clay as compared with sand support but it certainly is not inversely proportional to the supporting power of the subgrade soils.

The practical effect of this fundamental difference is shown by the wide range in depth required for macadam roads on different soils as compared with the small required range in strength of rigid pavements laid on these same varying soils.

From the standpoint of comparative construction costs, macadam generally has a distinct advantage over rigid pavements where the subgrade supporting power is high, which permits relatively thin macadam construction. It loses this advantage as the soils become poorer in supporting power, necessitating a large increase in macadam depth as against a small increase in rigid pavement strength. However, when

we reach a really unstable soil where settlement occurs over large areas, a rigid pavement is not feasible without the use of underlying macadam base and the macadam type regains its advantage.

TABULATION SHOWING APPROXIMATE EFFECT OF FOUNDATION SOILS ON THE RELATIVE CONSTRUCTION COSTS OF TYPICAL BITUMINOUS MACADAM AND CEMENT CONCRETE PAVEMENTS UNDER CLASS II TRAFFIC

Foundation soil	Approximate construction cost per square yard (1922)	
	Bituminous macadam	Cement concrete
Coarse sand and gravel	$2.00	$2.80
Loams	$2.30	$2.90
Clays (ordinary)	$2.60 to $3.40	$3.00 to $3.20
Wet clay sand quicksand	$3.00 to $3.80	$3.60 to $4.00

Effect of Temperature and Frost.—*Changes in temperature, except freezing, have no effect on macadam pavement design.*

Changes in temperature must be considered in rigid pavement design as they produce internal stresses resulting in contraction cracks and "blow ups," and produce warping which results in lack of uniform soil support for the slabs.

Frost heave very materially reduces the distributing power of macadam pavements for a short time in the spring by breaking the tight internal lock and it is at this time that most macadam failures occur as the subgrade is at its worst at the same time that the pavement has the least distributing power. *That is, in order to prevent failures entirely for a short time in the spring, macadam must be designed needlessly thick considering its distributing power for the balance of the year.* It is prohibitive in cost to design for this extreme combination of unfavorable conditions under heavy traffic on poor soils and in practice reasonably safe depth is provided with the idea of minor repair and some restriction on heavy loads for a short time in the spring.

Temperature changes do not affect the internal resisting moment of rigid pavements which is constant the year round but temperature changes produce slab distortion, cracks, etc., which increase the normal stress in the pavement. The effect of temperature must always be considered in rigid pavement design.

Effect of Traffic Loads.—Occasional extremely heavy loads far above the normal vehicle load are not disastrous to the macadam type as this type of road is more or less self healing and knits together again under rolling or well distributed normal load traffic. That is, *macadam roads can be safely designed for the normal maximum vehicle load.*

If a rigid pavement slab is cracked by exceptionally heavy loads, this crack is not self healing and it is very difficult to replace a portion of a

slab and get reasonable bond with the adjacent pavement. That is, *rigid pavement design must consider the exceptional load.*

This general fact tends to warrant a difference in design loading for the two types of pavement.

The Effect of the Critical Location of Loads.—Critical loading will be discussed in detail later. At this point we will anticipate the discussion by stating general conclusions in order to complete the comparison of the differences in design fundamentals. The location of wheel loads on macadam pavements which cause the worst distribution of pressure to the subgrade is along the edge of the macadam; at this location part of the distributing value of the macadam is lost; this does not have much effect where the shoulder is a well consolidated gravelly soil but for shifting sand or wet clays it helps cause the formation of a shallow rut along the edge on heavy traffic roads carrying a continuous double line of traffic (see Fig. 25). This, however only applies to Class I traffic roads and need not be considered in the design of Class II, III and IV roads as on these roads there are few cases where heavily loaded wheels follow close to the edge continuously enough to cause trouble. There is not much probability of adjacent wheel loads of passing rigs being close enough together to cause critical loads continuously in the central part of the road.

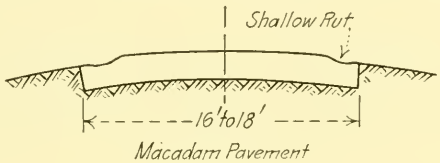


FIG. 25.—Typical shallow ruts along edge of Class I traffic macadam pavement.

Flexible base pavements on Class I roads must consider the critical location of load. Macadam pavements on Class II, III and IV roads are designed for the normal wheel load location.

On rigid pavements the critical location of wheel loads is at the corners of slabs. Such corners occur both at the pavement edge or at internal points due to longitudinal joints or temperature cracks (see Fig. 41, page 104). Wheel loads at critical points occur quite continuously at internal corners and with moderate frequency at outside corners on heavy traffic roads. *Rigid pavement design is predicated on utilizing critical load location in designing strength.*

Effect of Future Resurfacings on Strength Factor of Safety.—The strength of a macadam road can be increased at any time by the construction of a new top course on the old road. The distributing power of macadam varies about as the square of the depth and it makes no difference whether the different layers are constructed at the same time or at intervals. This means that if at any time the loading on a macadam road increases or if the original construction proves too weak for increasing

traffic that the pavement can be strengthened without much loss in total final cost. This warrants using a low factor of safety in original strength design.

While the resurfacing of rigid slabs adds something to their strength, the construction of successive layers is not an effective way to increase beam or slab strength. Rigid slabs must be originally constructed at least amply strong for existing traffic and some provision may well be made for heavier future traffic. That is, the factor of safety should be somewhat higher than for macadam design.

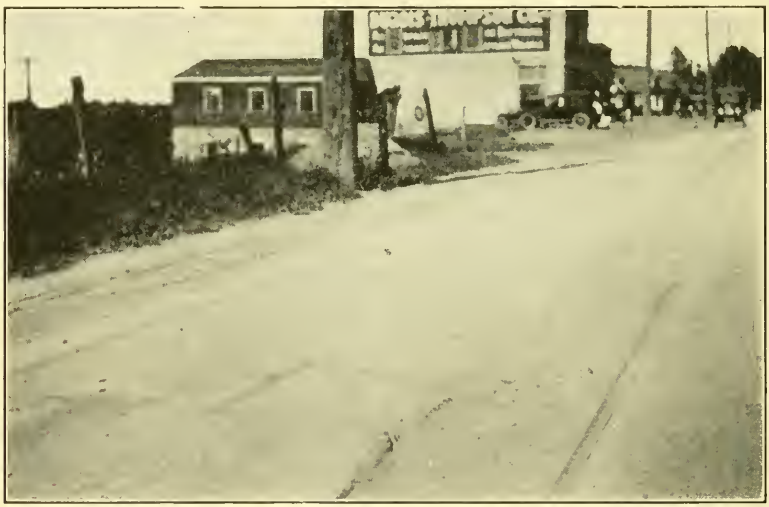


FIG. 26.—Typical corner crack, plain concrete pavement. This pavement is an 8-in., depth 1: 1½: 3 cement concrete on sandy soil. It carries a large volume of heavy gravel trucks loaded to the maximum legal limit of 28,000 lb. gross weight.

Effect of Construction Imperfections.—The strength of pavements depends largely on the excellence of construction and some allowance must be made in design for common imperfections.

Macadam is less damaged by careless manipulation than rigid pavements. The settlement of new fills causes more cracking of rigid pavements than any other factor.

SUMMARY OF FUNDAMENTAL FACTORS IN DESIGN

MACADAM TYPES	RIGID TYPES
1. Soil support is utilized at all points.	1. Soil support cannot be utilized at all points.
2. Full soil support can be utilized.	2. Full soil support cannot be utilized.
3. The soil support used must be lowest value considering seasonal variation.	3. Seasonal variation of soil supporting power has only a minor effect.
4. Macadam strength varies at different times.	4. Rigid slab strength is constant.

SUMMARY OF FUNDAMENTAL FACTORS IN DESIGN—*Continued*

Macadam Types	Rigid Types
5. Occasional excessive loads need not be considered.	5. Occasional excessive loads must be considered.
6. The special location of loads need only be considered in a few cases.	6. The special location of loads must always be considered.
7. Temperature stresses need not be considered.	7. Temperature stresses must be considered.
8. A comparatively low factor of safety is warranted.	8. A fairly liberal factor of safety is necessary.
	9. Rigid pavements composed of separate concrete base and resilient surface courses reduce impact damage and warping due to daily temperature fluctuations and increase wheel load distribution over base cracks.

If the design of either macadam or rigid pavements provided for the most extreme combination of unfavorable conditions for every factor involved, the pavement would be prohibitive in cost. It is apparently sound policy to provide for probable combinations of unfavorable conditions and plan on minor repair for a small percentage of failure. Reasonable design hinges on the assignment of proper values for the various factors of wheel load, supporting power of soils, distributing power of macadam pavements and slab strength for rigid pavements.

Traffic Loads.—The maximum loading on pavements is produced by the modern commercial truck traveling at high speed. Horse-drawn farm vehicles and the ordinary passenger automobile can be disregarded as far as the load factor is concerned. Even military field ordinance loads are no more severe than the commercial truck loading.

Statutory limitations on load, speed and various other factors are necessary to insure against the needless destruction of pavements. Existing statutes limit vehicle gross load, axle load, wheel load, load per lineal inch of tire width and speed. Such statutes may well be broadened to include limitation of the use of heavy trucks to Class I and II roads and also various factors in truck operation which increase impact such as badly worn tires, spring equipment, etc. While local statutes vary, the essential features have been standardized by common agreement to approximately the following values (1923 for Commercial Highways):

Maximum gross weight 22,000 to 28,000 lb.

Maximum wheel load 8,000 to 10,000 lb. (Weight at rest.)

Maximum load per inch width of tire 600 to 800 lb.

FIG. 27.—Excessive traffic loading.

FIG. 28.—Normal heavy traffic.

LIMITATIONS OF TRUCK LOADS ON HIGHWAYS (1923)

STATE	MAXIMUM GROSS WEIGHT IN LBS. (4 WHEELS)
Alabama	20,000
California	30,000
Colorado	16,000
Connecticut	25,000
Delaware	22,000
Florida	16,000
Indiana	24,000
Illinois	32,000
Iowa	20,000
Maine	20,000
Maryland	20,000
Minnesota	28,000
Nevada	25,000
New Hampshire	20,000
New Mexico	12,000
New York	28,000
North Carolina	15,000
Ohio	20,000
Oregon	22,000
Pennsylvania	26,000
South Dakota	20,000
Tennessee	20,000
Texas	22,000
Utah	20,000
Vermont	12,500
Virginia	20,000
Washington	24,000
Wyoming	25,000

The Pennsylvania (1921) Law is representative of the usual solid tire truck speed regulations.

Class	Gross load, pounds	Speed, miles per hour
AA	7,000	20
A	11,000	20
B	15,000	18
C	20,000	15
D	24,000	15
E	26,000	12
F	26,000	10

These legal load limitations do not represent design loads as impact increases the static load of a truck at rest. For well maintained moderately smooth pavements, however, the effect of impact does not probably add over 25 per cent to the static wheel load at rest for the larger trucks travelling at legal speeds (see Table 11, U. S. Bureau of Public Roads

TABLE 11.—IMPACT CAUSED BY DIFFERENT MOTOR TRUCKS
U. S. Bureau of Public Roads

Rated capacity of truck, tons	Load, tons	Load on one rear wheel			Equivalent static load for different heights of fall		
		Total	Sprung	Unsprung	0	¼ in.[1]	1 in.
1½	1½	3,475	2,410	1,065	5,500	7,800	10,200
1½	1½	3,475	2,410	1,065	4,500	6,300	11,500
1½	2¼	4,240	3,175	1,065	4,700	10,000	16,000
1½	2¼	4,240	3,175	1,065	4,900	5,900	9,200
2	2	4,300	3,300	1,000	6,800	7,800	11,500
2	2	4,300	3,300	1,000	6,800	8,500	13,400
2	2	4,300	3,300	1,000	6,800	7,900	11,000
2	2	4,300	3,300	1,000	6,800	7,500	11,000
2	3	4,900	3,900	1,000	7,200	8,500	14,000
2	3	4,900	3,900	1,000	7,300	8,600	13,700
2	3	4,900	3,900	1,000	6,800	8,000	11,000
3–3½	2½	5,150	3,450	1,700	8,400	9,200	15,700
3–3½	2½	5,150	3,450	1,700	8,200	8,700	11,800
3–3½	2½	5,150	3,450	1,700	8,200	9,300	14,100
3–3½	2½	5,150	3,450	1,700	6,900	9,200	21,500
3–3½	2½	5,150	3,450	1,700	8,000	8,200	12,200
3–3½	2½	5,150	3,450	1,700	8,700	8,200	13,000
3–3½	4½	7,000	5,300	1,700	.....	10,000	19,000
3–3½	4½	7,000	5,300	1,700	9,700	9,700	19,000
3–3½	4½	7,000	5,300	1,700	9,300	9,800	17,700
3–3½	4½	7,000	5,300	1,700	9,200	11,000	17,200
3–3½	4½	7,000	5,300	1,700	10,000	10,000	18,000
3–3½	4½	7,000	5,300	1,700	10,000	11,000	15,800
5	5	7,900	5,950	1,950	11,000	12,800	18,000
5	5	7,900	5,950	1,950	11,000	12,500	19,000
5	5	7,900	5,950	1,950	9,000	10,000	16,000
5	5	7,900	5,950	1,950	9,200	10,700	15,500
5	5	7,900	5,950	1,950	9,200	9,700	13,000
5	5	7,900	5,950	1,950	9,500	.....	15,000
5	7½	10,600	8,650	1,950	12,200	15,300	26,000
5	7½	10,600	8,650	1,950	12,000	13,700	21,000
5	7½	10,600	8,650	1,950	11,500	12,500	18,500
5	7½	10,600	8,650	1,950	11,500	12,600	17,200
5	7½	10,600	8,650	1,950	11,000	11,200	16,800
5	7½	10,600	8,650	1,950	11,200	12,100	15,800

[1] The ¼-in. column is assumed to represent probable impact on well maintained roads. See also page 150, Vialog Records.

Impact Tests). For the smaller solid tire trucks at higher speeds, it may add 100 per cent. For pneumatic tire trucks, it does not probably exceed 10 per cent on the average. The tests recorded some cases of 400 to 500 per cent increase due to impact, but these represented conditions of roughness that would not occur on well-kept pavements. The extreme loads resulting from impact on rough surfaces emphasize the necessity for the construction of reasonably smooth pavements properly maintained. *It would be impracticable to design pavements on the basis of high impact stresses.* Attention should be concentrated on the reduction of impact to the minimum feasible amount which is assumed to be represented by the ¼- in. column of Table 11 for the smoother pavements such as modern macadams, sheet asphalt, grouted brick and concrete and a somewhat higher value for the rougher types such as stone block, brick with bituminous filler, etc. Vialog records discussed on page 150 indicate that the ¼-in. impact is a reasonable basis of design.

The tractive effort of mechanically propelled vehicles is a surface shearing force and can be disregarded in deriving design loads for pavement strength formulae. It has some effect in producing humps and hollows in asphaltic concrete and bituminous macadam surfaces and probably hastens disintegration of bond between poorly bound block surfaces.

Recommended Design Loads.—It seems rational to recognize at least two load classifications due to general character of traffic and also variations due to pavement surfaces.

Class I and II Main Roads.—These roads should be designed for the heaviest commercial trucks permitted by law. It is probable that a design wheel load of 14,000 lb. (11,000 lb. static plus 3,000 lb. impact) distributed over a 12-in. tire width represents about the maximum load produced by present day heavy traffic operating at legal speeds on well-maintained rigid pavements such as cement concrete, monolothic or semi-monolithic brick with cement grout joints on concrete base, etc. Pavements having a surface or base which has some flexibility and resiliency are undoubtedly less damaged by impact than the more rigid types. How much weight can be given to this in design is not known but in order to recognize this factor it is well to adopt a slightly lower value than shown in Table 11. Twelve-thousand pounds on a 12-in. tire will be assumed for bituminous macadams, small blocks with asphaltic joints on macadam bases and asphaltic concrete surfaces on either macadam or concrete bases. For the rougher pavements such as stone block or brick with bituminous joints on concrete bases, a value of 15,000 to 16,000 lb. is probably not excessive.

Class III and IV Local Roads. (Macadam Design).—For these roads a lower design load is logical. A total of 9,000 lb. (5,000 lb. static plus 4,000 lb. impact) on a 10-in. tire is liberal and a design allowance of 7,000 lb. on a 10-in. tire width is probably about the desirable maximum

limit for purely local roads carrying less than 300 vehicles daily. Class III and IV roads are at times subjected to heavy truck Class I loading under existing traffic regulation statutes but it is probably sound policy to use the lighter design loading and make an effort to modify existing regulation to the extent of keeping the heavy trucks off from these local roads particularly in the spring. While it is probably impossible entirely to prevent heavy trucks from violating such statutes, an occasional violation is not serious as noted under general basis for design of macadam roads, page 74. The recommended loading permits all year round use of the ordinary 2½-ton agricultural trucks and gives sufficient strength in the summer season to permit the use of these roads as temporary detours for heavy traffic at times when the main roads are closed on account of construction or repair.

TABLE 12.—RECOMMENDED DESIGN LOADS

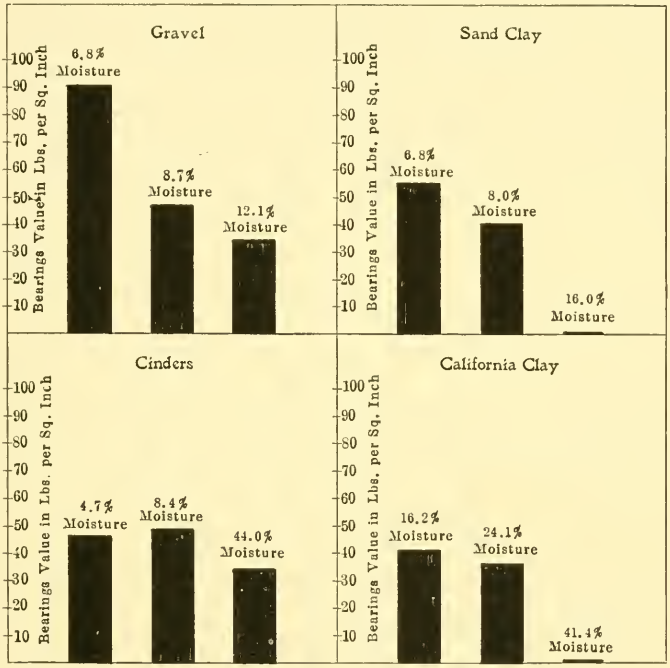
Class of road	Design static wheel load (including impact)
Classes I and II	16,000 lb. on 12-in. tire, rougher types rigid pavements. 14,000 lb. on 12-in. tire, smooth rigid pavements. 12,000 lb. on 12-in. tire, resilient pavements.
Class III	12,000 lb. on 12-in. tire, rigid pavements. 9,000 lb. on 10-in. tire width, macadam pavements.
Class IV	7,000 lb. on 10-in. tire width, macadam pavements.

These concentrated wheel loads must be transmitted by the pavement and applied to the underlying earth subgrade over a large enough area to prevent rapid unequal settlement or permanent displacement.

Supporting Power of Soils.—Different soils have a wide range in supporting power and even the same soil varies greatly at different times due to moisture content, freezing action and degree of consolidation. Road foundation soils fluctuate more in their supporting power than deep foundation soils for buildings as they are near the surface and are subject to the effect of rain, frost and the churning action of rapidly fluctuating loads.

Pavement design to be rational and fairly consistent must consider variations in the supporting power of the underlying subgrade, but it can only consider such differences in soil conditions as are clearly defined. It is impracticable to give much attention to minor variations; that is, for a specific road, the supporting power of soil varies foot by foot and even for the same point it changes at different times in the year. For these reasons, any attempt to apply laboratory methods to rapidly fluctuating subgrade conditions is impracticable to say the least. It is feasible to

provide changes for well-defined differences in soil conditions which become evident to an experienced highway engineer during the progress of the survey and construction. It is practicable to eliminate excessive ground water seepage by the use of underdrains and to reduce surface water seepage by well-constructed and well-maintained shoulders and ditches and by the constant sealing of cracks in rigid pavements. Even with these precautions, water will work in from the shoulders or reach the subgrade through cracks in the pavement and in this way temporarily reduce the supporting power of the earth subgrade. All pavement and foundation design must be predicated on the fact that the supporting



Note: Above Values are for 0.2" Penetration and 30 Lbs. per Sq. In. Initial

FIG. 29.—Effect of moisture content on bearing power of soils. U. S. Bureau of Roads testing records.

power of the underlying earth will vary at different times and the important factor in design is minimum supporting power considering all year round conditions for local climatic conditions.

Experience has demonstrated that coarse sands and gravel do not vary much in supporting power at different seasons if protected by well-designed drainage. We know that loams, clays and fine sands vary considerably in supporting power where they are located in cuts or thin "pancake" fills even when protected by well-designed drainage and that these same soils in fills over 3 ft. deep do not vary much at differ-

ent seasons provided the pavement surface is reasonably waterproof and the shoulders are maintained to shed water rapidly. Figure 29 shows in a general way the effect of moisture content on the supporting power of different soils. Experience has demonstrated that under normal road conditions it is fairly easy to prevent a large variation in the moisture content of coarse sand and gravels and increasingly difficult to control the moisture content of loams, clays and quicksands. The vertical rise of moisture due to capillary action is shown in the attached table. Moisture content for road beds in cut is reduced by open ditches and under drains but these methods fail in effectiveness at times due to all sorts of reasons such as frozen drains and shoulders, poorly maintained shoulders permitting pools of water to stand and seep in and cracks in rigid pavements. Where the road is in cut or on thin fills we are certain to get at times a higher moisture content than where the roadbed is on a high fill which is free from ground water seepage and above the limits of vertical capillary lifting action. *As macadam design utilizes full support; it must not only recognize the difference in soils but it must also recognize whether the soil is in cut or fill.*[1]

Table of Height to Which Capillary Water Rises in Different Soils
(Experiments by U. S. Bureau of Public Roads)

Soil	Height in 24 Hours Inches	Approx. Final Height Inches
Light sandy soil	14	28
Gravelly soil	16	32
Decomposed granite (loam)	21	40
Heavy granite loam	16	32
Clay loam	12	24
Pure coarse sand	9	18

The percentage of moisture due to capillarity decreases rapidly with the height above the free water for the coarse sandy soils while it remains nearly constant for the entire range of vertical capillarity in some of the heavier soils.

There seems to be fair agreement between widely different sources as to the minimum safe supporting power of well compacted subgrade soils protected by well-designed drainage provisions. The Massachusetts Commission in 1901 determined these values at 25 lb. per square inch for

[1] The fact that fills reduce required depth of macadam pavements does not affect grade line design as the reduction in cost of macadam rarely balances the increase in grading cost due to arbitrarily raising the road by fill. That is, the consideration of pavement depth and strength never raises the road on to fills except across low wet swampy areas. Needless fill adds danger to road traffic, always increases damage to abutting properties and is to be avoided as much as possible as it gives no adequate return. Where fills are necessary, their construction should be taken advantage of to reduce macadam depths but not rigid pavement depth. Most rigid pavement troubles occur on fills due to incomplete compaction before the pavement is constructed.

coarse sand and gravel and at 4 lb. per square inch for the poorer clays and excessively fine sands. French experiments quoted in Agg's Construction of Roads and Pavements place the values at 30 lb. per square inch for firm soils and at 9 lb. per square inch or less for the poor soils. These values are for well-compacted soils and refer to well-rolled subgrade soils kept free from an excessive moisture content by a well-designed drainage system. The necessity for thorough rolling of the subgrade is well recognized. Table 13 compares these values with the usual value assigned to these soils for deep building foundations and illustrates the radically different supporting value of surface and subsurface soils.

TABLE 13.—COMPARISON OF SAFE SUPPORTING VALUE OF SURFACE AND SUBSURFACE SOILS IN POUNDS PER SQUARE INCH

Soil	Road subgrade surface soils	Subsurface building foundations
Coarse sand and gravel	25 to 30	60
Poor damp clay and fine shifty sand (30 per cent or more passing 100 sieve)	4 to 8	15

The values of intermediate soils and the effect of fills are largely a matter of judgment and experience. The following recommended values are based on the observed action of roads in Western New York during the past 15 years. These values are to be used in conjunction with Formula 1, page 91, and are safe values for localities subject to severe winters. They can undoubtedly be increased for locations free from frost; no special values are given for such conditions as the author's personal experience does not warrant assigning values for other than climates similar to the northeastern Atlantic states. In the course of time, values for various localities will become more or less standardized. With this in view it is desirable for the various Highway Departments to make a systematic effort to record failures and successes as shown in chart form Fig. 35, page 96. One of the difficulties to overcome in public highway work is the effect of rapidly changing personnel. If data is not systematically recorded, the value of experience is lost and the new men have to start in all over again to gather data. Up to date this has been one of the main difficulties.

It can be readily seen that the classification of the soils is largely a matter of judgment but it is entirely feasible to educate a beginner very rapidly to distinguish between the general classifications noted in the above table. In the author's opinion any attempt to classify subgrade soils during construction by laboratory methods is too costly and compli-

TABLE 14.—RECOMMENDED SAFE SUPPORTING POWER OF SUBGRADE SOILS IN POUNDS PER SQUARE INCH FOR LOCALITIES SUBJECT TO SEVERE WINTERS

(For Use in Connection with Formula 1, page 91)

Soil	Location		
	In cut or on fills less than 1 ft. deep	Intermediate fills, 1 to 3 ft. deep	High fills over 3 ft. deep
Fine sand (more than 30 per cent passing 100 sieve)	4 to 8	8 to 15	15
Heavy clay	4 to 8	10 to 17	17
Ordinary clay	8 to 13	13 to 19	19
Clay loam	13 to 17	17 to 20	20
Loam	17 to 21	19 to 21	21
Sandy loam	21 to 25	23 to 25	25
Coarse sand	25 to 30	27 to 30	30
Fine gravel	25 to 30	27 to 30	30

cated a process to have much practical value. If the design of macadam is based on the above general classifications, the chances are all in favor of reasonably good results, particularly if the grading operations are controlled and the fills under the pavement made fairly uniform and of the best available material.

Theoretical Design of Macadam Road Thickness.—The determination of thickness depends on the wheel loads, the supporting power of the underlying soil and the distributing action of the macadam pavement. Wheel loads and the supporting power of soils have been determined within reasonable limits of accuracy. These determinations are based both on experiment and the observed action of macadam pavements under actual traffic which indicates quite strongly that they are essentially correct. It remains to discuss the distributing power of macadam pavements and assemble the factors with a reasonable factor of safety.

Distributing Action of Macadam, Gravel and Boulder Bases.—Experimental data in regard to the load distribution through flexible type bases is meagre. Table 15 taken from Agg's "Construction of Roads and Pavements" records certain French data which is probably as reliable as any investigations which have been made up to this time (1922). Figures 30 and 31, page 87, show recent tests made by the United States Bureau of Public Roads at Washington.

The distributing action of broken stone macadam is slightly better than telford or boulder base. The distributing action of well-constructed

gravel courses is usually as good if not better than boulder base although not quite as effective as macadam. The distributing power of all these

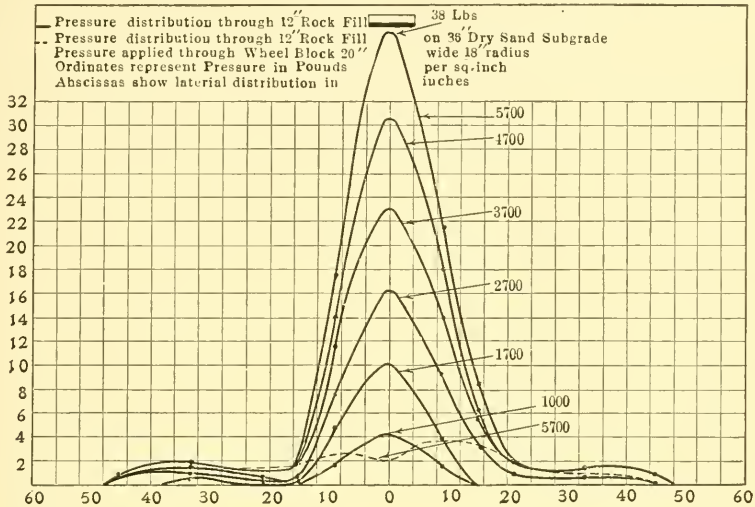


FIG. 30.—Distribution of pressure through macadam laid on sandy soil. U. S. Bureau of Roads experiment.

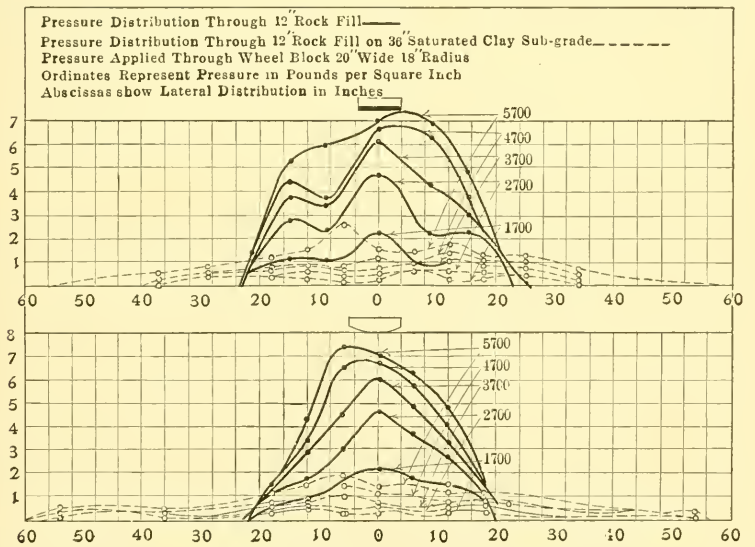

Pressure Distribution Through 12" Rock Fill
Pressure Distribution Through 12" Rock Fill on 36" Saturated Clay Sub-grade
Pressure Applied Through Wheel Block 20" Wide 18" Radius
Ordinates Represent Pressure in Pounds per Square Inch
Abscissas show Lateral Distribution in Inches
5700
4700
3700
2700
1700

FIG. 31.—Distribution of pressure through macadam pavement clay sub-soil. U. S. Bureau of Roads experiment.

types depends on the excellence of construction (degree of tight interlock and compaction) and for each type it will vary at different times of the year the least value occurring in the spring when the tight internal lock

is reduced by frost heave. In order to provide the proper thickness of macadam it is necessary to determine the effect of depth on total area of subgrade over which the wheel load is distributed and the ratio of maximum intensity of pressure directly under the wheel to average intensity over the total area of subgrade receiving pressure.

TABLE 15.—SHOWING TRANSMISSION OF PRESSURE THROUGH MACADAM

The test was made with a wheel load of 4 tons with a 5½-in. tire.

On macadam alone:					
Thickness of crust, inches	1.97	3.94	5.91	7.87	11.81
Pressure on subsoil, pounds per square inch	102.50	47.70	27.40	17.40	9.10
On telford foundation alone;					
Foundation thickness, inches			5.91	7.81	11.81
Pressure on subsoil, pounds per square inch			56.00	37.40	20.70
On combined foundation and macadam:					
With foundation thickness of, inches		5.91	7.87	9.84	11.81
3.94 in. of top stone, pressure on subsoil, pounds per square inch		19.30	14.70	12.60	10.20
5.91 in. of top stone, pressure on subsoil, pounds per square inch		13.20	10.90	9.10	7.70
7.87 in. of top stone, pressure on subsoil, pounds per square inch		9.70	8.20	6.80	6.10

The pressure on the subsoil through a 12-in. bed of simple macadam is apparently the same as the pressure through a 6-in. bed of macadam laid over a 10-in. stone foundation. A good soil well drained will safely withstand a pressure of 30 lb. per square inch.

It is considered that poor soil requires at least a 12-in. macadam layer or its equivalent.

The pressure transmitted by well-constructed gravel will be about the same as with macadam of equal thickness.

Figures 30 and 31 show that for a given depth of macadam and a certain specified load the maximum intensity of pressure directly under the wheel is greater for firm soils such as dry sand than it is for soft subgrades such as wet clay; that the ratio of maximum pressure to average pressure is greater on firm soils and that the total area of load distribution is slightly less on firm soils than on soft subgrades. This merely means that firm soils offer greater unit resistance and that for the condition of a certain specified depth of macadam and a specified load the deflection of the macadam under the wheel is less on the firm subgrade than on the soft subgrade. These variations in the law of pressure distribution disappear in any rational formulae for macadam design for the following reasons. A well-designed macadam road must not have much deflection under a moving wheel load for the minute noticable deflection occurs (so called churning) the pavement starts to disintegrate and either gets out of shape rapidly or completely goes to pieces. Some deflection is bound to occur but the basic principle of good design requires variation in stone depth over different soils so that the maximum wheel

load produces a fairly uniform deflection at all points. This deflection must be small enough to prevent churning. If the road is properly designed with a uniform and safe deflection the relation of depth to distribution area and the ratio of maximum intensity of pressure to average intensity are not probably much affected by the character of the subsoil. At least we know from practical experience that simple empirical formulae, which consider variations in wheel load, a fairly well established relation between depth and intensity of pressure on the subgrade and

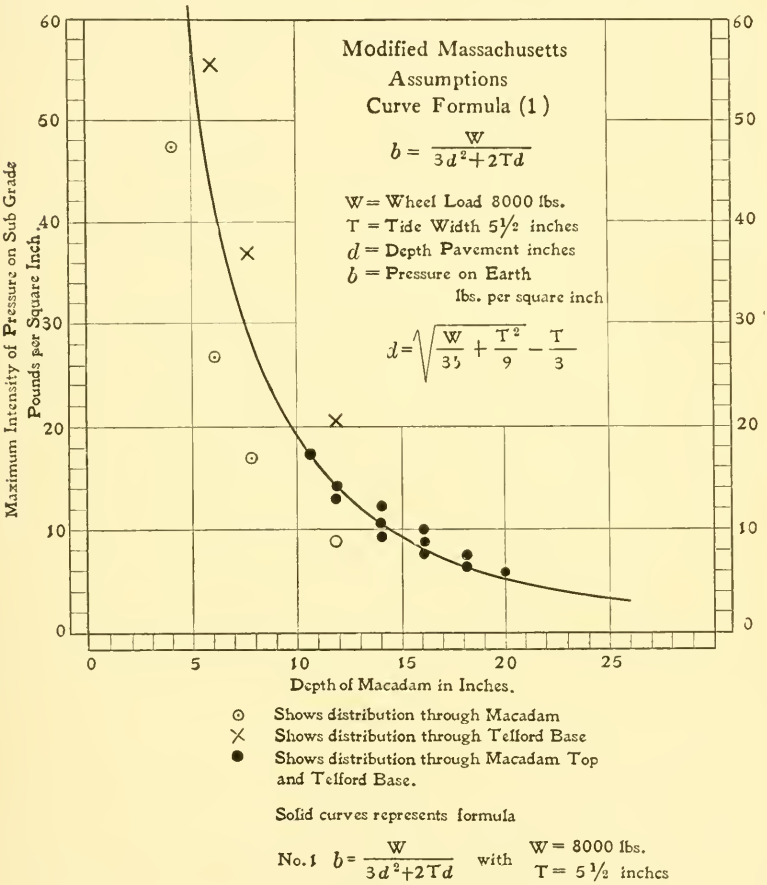


FIG. 32.—Graphic comparison of Formula 1 (solid curve) with French experiments recorded in Table 15 (plotted by crosses, circles and dots).

reasonable values for safe supporting power of soils, have been developed and that such formulae have been given sufficiently hard and long enough continued service tests to warrant their use as a basis of economic macadam design.

We propose to use an old and simple rule as the basis of a practical formula: Namely the Massachusetts rule of 1901. "The pressure is

distributed through macadam and any ordinary gravel or boulder base at an angle of 45° with the horizontal and the resultant maximum intensity of pressure on the subgrade amounts to the load at any point divided by the square of twice the depth of the pavement." While this is rather a rough and ready rule its application produces as good results as any basis of comparison provided it is slightly modified to consider width of wheel. Formula 1 makes such minor modifications. A comparison of Formula 1 with the French experiments (Table 15) is shown in graphic form in Fig. 32 and indicates essential agreement as far as practical results are concerned with the added indication that Formula 1 is on the safe side for the usual combinations of macadam top and boulder bases.

Research Engineers are not likely to heartily approve of this formulae as it is not a very scientific product but its simplicity, its essential agreement with experimental data, and the excellent results obtained in actual construction from its use are strong arguments in its favor.

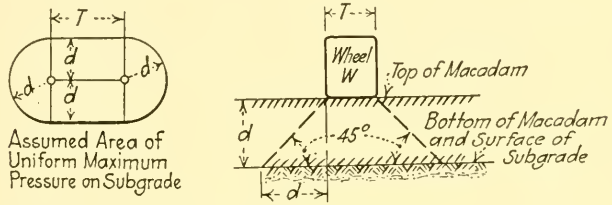
Basic Assumptions (*Formula* 1). *Area Uniform Maximum Pressure.* An hypothetical area of uniform maximum pressure is determined by a line at an angle of 45° from the outer limits of wheel contact. This of course does not represent actual conditions but it is on the safe side. The pressure caused by a wheel load is not uniformly distributed over the subgrade (see Figs. 30 and 31, page 87). The maximum pressure occurs directly under the wheel and gradually fades away to nothing at a variable distance from the point of load. The assumption used, gives the same total resistance to the wheel load but contracts the actual area of the subgrade receiving variable pressure to a hypothetical area over which the maximum pressure occurring directly under the wheel is considered as uniform. The essential correctness of the 45° limit of uniform maximum pressure can be seen from Figs. 30, 31 and 32. By this means the value for safe supporting power of soils can be used directly.

This area of maximum uniform pressure depends on area of wheel contact which depends on width of tire and length of contact along the road. The width of tire is a definite dimension, recognized and limited in statutory load regulations. The length of tire bearing along the surface is variable depending on the size of the wheel and on the type of tire and load. For steel-tired wheels, it is small, probably not over an inch. For solid-tired heavy commercial trucks, it is a larger value. Due to the facts that the steel-tire load is liable to occur and that the length of contact is variable for rubber tires, this dimension will be neglected and knife-edge contact for the full width of the tire will be used. This gives results on the safe side and in effect usually introduces a factor of safety of about 10 to 25 per cent. It is also assumed that the wheel load is far enough from the edge of the pavement to get full distribution for

the entire depth of pavement. Modifications for edge loading are considered in Formula 2.

The formulae for depth of macadam is developed on the basis outlined.

W = Static wheel load in pounds plus impact allowance.
T = Width of tire in inches.
d = Depth of pavement in inches.
b = Maximum pressure on subgrade due to wheel load in pounds per square inch.



Area of uniform distribution of maximum pressure $= \pi d^2 + 2dT$
$= 3.14d^2 + 2dT$
$= 3d^2 + 2dT$ for all practical purposes

Formula 1

$$b = \frac{W}{3d^2 + 2dT}$$

$$d = \sqrt{\frac{W}{3b} + \frac{T^2}{9}} - \frac{T}{3}$$

Modification of Formula 1 for Special Location of Wheel Loads.—A typical maximum load condition is shown in Fig. 33 for an 18-ft. double track road. This is a rare occurrence as when trucks pass, they want all the clearance they can get and they hug the edge of road (Fig. 33*B*).

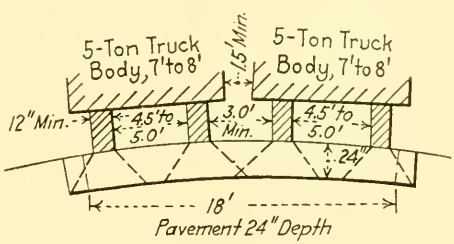


FIG. 33*A*.—Location of passing vehicles for critical load in center of macadam.

These sketches indicate roughly that there is not much probability of enough overlap of pressure zones from adjacent wheels in the center of a road to produce a greater pressure than the maximum directly under

the wheel for ordinary depths of macadam on ordinary soils; for extreme depth on very poor soils such an overlap may occur but it would require a very unusual combination of unfavorable conditions to make this continuous enough to cause trouble.

On the side of the road, however, edge loading is a very common and continuous condition on Class I roads but occurs only at intervals along

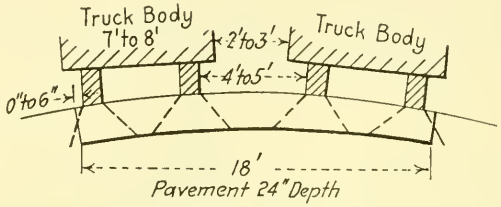


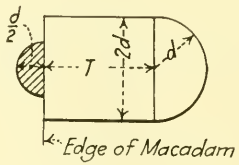
Fig. 33*B*.—Location of vehicles. Critical loading at edge of pavement.

the road and only at time intervals on Class II, III and IV roads. This critical condition of side load must be considered if the macadam type is used on Class I roads. As previously stated, the use of macadam is inadvisable on Class I except for special conditions in reconstruction programs. Formula 1 need not be modified for Class II, III and IV roads but probably should be modified for Class I roads.

Any modification is purely guess work and is made more to point out and recognize the effect of critical loading on Class I than for any other reason. Under the worst possible conditions eliminating all distributing action by the shoulder material, the supporting area may be assumed as

$$2dT + \frac{\pi d^2}{2} \qquad \text{Say } 2dT + 1.5d^2$$

This is probably entirely too low a value and to approximate conditions and give some value to shoulder support, we will assume the area at



$$2dT + 1.5d^2 + \pi\left(\frac{d}{2}\right)^2$$

$$\text{Say} = 2.25d^2 + 2dT$$

Using this value Formula 1 becomes

Formula 2
(Class I Traffic)

$$b = \frac{W}{2.25d^2 + 2dT}$$

$$d = \sqrt{\frac{4W}{9b} + \frac{16T^2}{81}} - \frac{4T}{9}$$

Formula 1
(Class II, III and IV Traffic)

$$b = \frac{W}{3d^2 + 2dT}$$

$$d = \sqrt{\frac{W}{3b} + \frac{T^2}{9}} - \frac{T}{3}$$

Utilization of Formulae 1 and 2 in Macadam Pavement Design.— To utilize these formulae, it is necessary to assemble the values for load, supporting power of soils, and to discuss the factor of safety desired. Load and distributing power of macadam when tight locked are reasonably certain. Live load will vary according to the traffic the road will have but for all practical purposes, it is safe to use the statuatory limitation plus an allowance for impact. The values given on page 82 contain a small factor of safety. Dead load of the pavement itself can be safely disregarded unless we are dealing with muck or swampy foundation. The formulae developed for distribution of pressure assumes the same distribution for all the usual combinations of base and top courses and disregards reduction in distributing power due to frost action for a short time in the spring. Figure 32 indicates that for the usual combinations of base and top, these formulae are on the safe side but this factor is probably balanced by the unknown reduction in distributing power during the spring break up. Safe soil-supporting power is the most indefinite factor in the problem. As this factor is largely a matter of personal judgment, the values assigned for supporting power of soil can provide the desired factor of safety in the result. The values given on page 86 were adjusted for use in conjunction with this formula; it will be noted that the values used for the extreme conditions of good and bad agree closely with the Massachusetts and French values. The intermediate values are based on our experience in Western New York for a number of years. The use of these values for districts similar to Western New York will give reasonable results. There will be some spring failures but not many and for the balance of the year the factor of safety is high.

Figures 34*A*, 34*B* and 34*C* show graphically the depths of macadam obtained by the use of Formulae 1 and 2 with the recommended live loads given on page 82 and the soil values given on page 86. The suitability of these curves for any district can be easily determined by plotting on a chart the record of actual road failures for the district in question. If the curve derived from Formula 1 (using the local load limitation) is very much above the average run of actual blow ups, it can be lowered to get a reasonable percentage of failure; that is, this

curve should about fit the upper limit of depth for the usual failure on the different soils. A few exceptional cases can be disregarded. The data of actual road failures should be charted in a similar way to the usual chart of storm intensity in deriving storm sewer design assumptions. The method is illustrated by Fig. 35, page 96. Figure 35 is a record of observations in Western New York, 1907 to 1920.

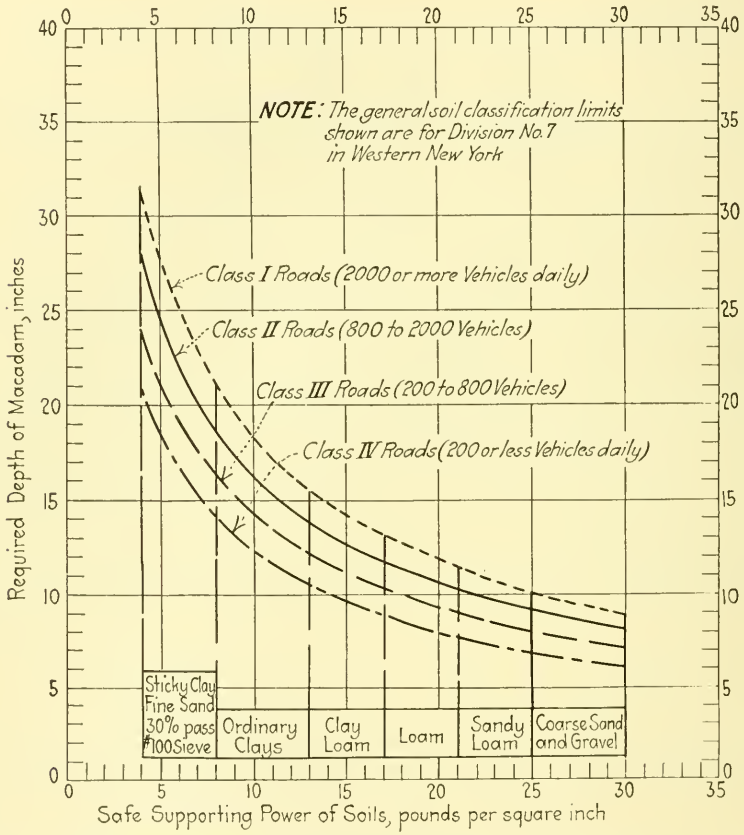

NOTE: The general soil classification limits shown are for Division No. 7 in Western New York
Class I Roads (2000 or more Vehicles daily)
Class II Roads (800 to 2000 Vehicles)
Class III Roads (200 to 800 Vehicles)
Class IV Roads (200 or less Vehicles daily)
Sticky Clay Fine Sand 30% pass #100 Sieve
Ordinary Clays
Clay Loam
Loam
Sandy Loam
Coarse Sand and Gravel
Required Depth of Macadam, inches
Safe Supporting Power of Soils, pounds per square inch
0
5
10
15
20
25
30
35
40

FIG. 34A.—Recommended depths of macadam pavements on different soils where the pavement is located either in cut or on fills less than 1 ft. deep.

Formulae 1 and 2 reduce to the following form if the design loading recommended on page 82 is used.

Class I Roads $\qquad d \text{ (depth macadam)} = \sqrt{\frac{48{,}000}{9b} + 28} - 5.3$

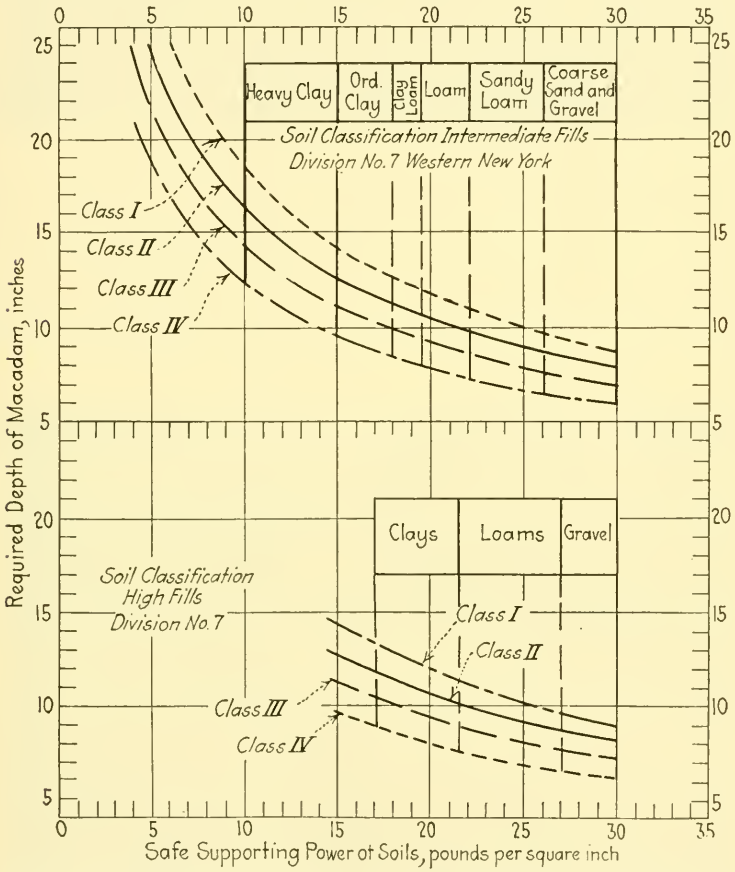
Class II Roads $\qquad d = \sqrt{\frac{12{,}000}{3b} + 16} - 4$

Class III Roads $$d = \sqrt{\frac{9{,}000}{3b}} + 11 - 3.3$$

Class IV Roads $$d = \sqrt{\frac{7{,}000}{3b}} + 11 - 3.3$$

These formulae are used in the preparation of Figs. 34*A*, 34*B* and 34*C*.

Experience with Various Depths of Macadam in Western New York. The first roads built in this section (from 1898 to 1902) were quite uniformly 6 in. in thickness over all kinds of soils. This was admitted to be



FIGS. 34*B* and *C*.—Recommended depths of macadam pavements located on fills. Intermediate fills (1 to 3 ft. deep). High fills (over 3 ft. deep).

rather irrational design but the cost had to be kept down and it was considered better policy to plan on more or less failure with consequent repair rather than spend more to insure against minor failure. As experience was gained, the depths were varied somewhat over different soils but these depths were in all cases much less than are ever used today.

The growth in motor traffic with heavier loads and more vehicles has resulted in the failure of most of these old thin macadams and the old roads have been gradually strengthened by the addition of extra courses of stone to meet the increased loads. By observation of these successive thickenings, the State Department of Highways has had a very excellent

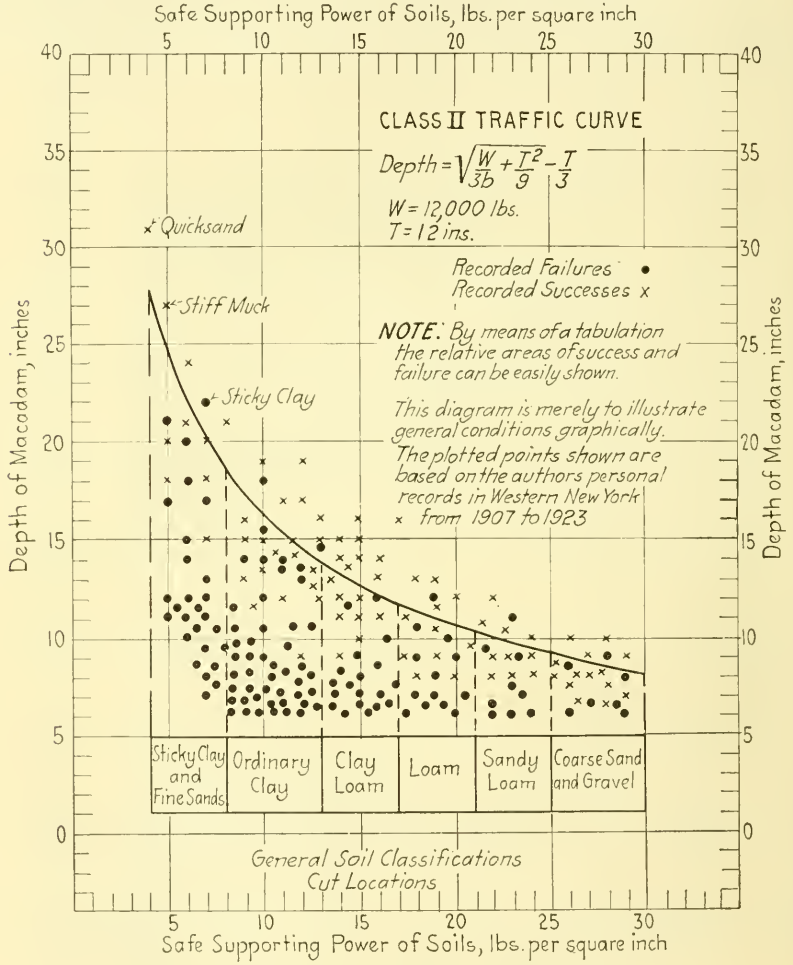

Safe Supporting Power of Soils, lbs. per square inch
CLASS II TRAFFIC CURVE
Depth = $\sqrt{\frac{W}{3b} + \frac{T^2}{9}} - \frac{T}{3}$
W = 12,000 lbs.
T = 12 ins.
Quicksand
Stiff Muck
Sticky Clay
Recorded Failures •
Recorded Successes x
NOTE: By means of a tabulation the relative areas of success and failure can be easily shown.
This diagram is merely to illustrate general conditions graphically.
The plotted points shown are based on the authors personal records in Western New York from 1907 to 1923
Depth of Macadam, inches
Sticky Clay and Fine Sands
Ordinary Clay
Clay Loam
Loam
Sandy Loam
Coarse Sand and Gravel
General Soil Classifications
Cut Locations

Fig. 35.—Comparison of theory with record of actual successes and failures.

opportunity of drawing reasonable conclusions as to the depths required for handling modern traffic on different soils.

There has, however, been no systematic official effort to gather this data in a complete and convincing manner and what data is available is due to the individual efforts of a few of the engineers. Officially, the experience of 20 years has been thrown away as far as definite tabulated data goes in regard to economical macadam depths under

different conditions. This is very typical of the attitude towards highway work in many cases and I have even heard some executives say that they didn't want to know too much about the economics of different types of pavements. This general attitude is being gradually dis-

A *B*

FIGS 36*A* and *B*.—Typical failures of thin macadam pavements on clay soil when subjected to continuous heavy trucking in the spring of the year. These pictures are of pavements near Rochester, N. Y., damaged by army truck traffic in 1918.

credited and we have hopes that in time an effort will be made to record the number of square yards of different depths on different soils with the yearly percentages of failure for the various depths and in this way gain

FIG. 37.—Road 5 New York State (15 years old) 5,000 vehicles daily (average mixed traffic). Successful macadam type pavement under heavy traffic, 8-in. total depth, 5-in. macadam base, 3-in. Amiesite top. Gravelly foundation soil.

some reliable means of balancing original cost against minor repair. This method has been used by various cities in determining economic depth of concrete foundations for street pavements.

The following statements summarize the experience and judgment of a number of the engineers of Division 7 who have kept records of successes and failures under the test of modern traffic including army trucking during the war.

Pavements 22 in. thick laid on poor clay and stiff muck soils have in a few exceptional cases rutted badly under Class II Traffic. Pavements 23 to 27 in. thick under similar soil and traffic conditions have retained their shape and have only required minor repair. This represents the worst soil conditions encountered in this territory. As a rule, a depth of 20 in. even on very poor clay holds Class II Traffic with only minor failures.[1]

On coarse sand and fine gravels, we have cases where a 7-in. depth is serving Class I traffic with no evidence of weakness but these are exceptional cases. As a rule, 9 in. is considered about the minimum serviceable depth for Class I on excellent soils.

For loams 7- to 8-in. depths have in some cases lasted well under Class II traffic but as a rule 10 to 12 in. is considered necessary to avoid too much maintenance.

For ordinary clays 9 in. often lasts quite well under Class II traffic but enough trouble has occurred even with 12-in. depth on these soils to warrant 15 to 18 in. as a reasonable design depth under Class II or III loading.

In order to coordinate this experience with other localities, the following table records range in macadam depths used by other states. Figure 35 shows a graphic method of charting successes and failures.

CURRENT PRACTICE IN MACADAM DEPTHS (1922)

TABLE 16.—RANGE IN MACADAM PAVEMENT DEPTHS

State	Minimum depth on firm soils, inches	Maximum depth on poor soils, inches
New York	8 (gravel soil)	12 to 30 quicksand
Rhode Island	6	9 to 20
Indiana[2]	11	14 or more
Pennsylvania[2]	9	12 or more
West Virginia[2]	8	12 or more
Arizona	6	Whatever needed
Wisconsin[2]	8	12 or more
California	6	Whatever needed
Washington	7	12 or more

[1] For deep macadams, the upper 3½ to 7 in. are usually broken stone macadam with the balance of the depth coarse gravel, boulders or telford subbase courses.

[2] The maximum depths given for these states do not indicate actual extreme maximums for short stretches of exceptionally poor soil conditions.

Effect of Soil and Total Depth on Selection of Foundation Courses for Macadam Pavements.—No matter what total pavement depth is required, the upper 3½ to 9 in. are usually of the true broken stone or broken slag macadam. Below this macadam, either stony gravel, boulder base or quarry stone telford can be used to get the total depth required with the least cost. If quicksand or wet clay is encountered, at least 6 in. of cinders or gravel should be placed as the lowest layer in order to blanket the soil and prevent its working up into the stone courses. Above this either gravel or boulder base or telford can be used capped with the usual broken stone bottom and top courses. In case gravel subbase is used for the entire depth of subbase, at least 5 to 9 in. of macadam must be used for the cap as it is not safe to produce a pressure of over 30 lb. per square inch on fine gravel without danger of rutting and the object of the overlying macadam is to reduce wheel pressure to this value (see Fig. 34*A* gravel soils). If the gravel subbase is exceptionally coarse stony gravel, it is safe to reduce the macadam cap thickness to 4 in. for Class IV roads and to 8 in. for Class I roads. If

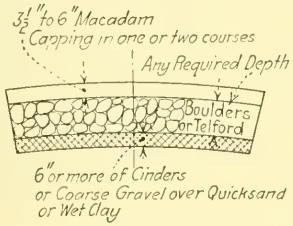

3½" to 6" Macadam
Capping in one or two courses
Any Required Depth
Boulders or Telford
6" or more of Cinders or Coarse Gravel over Quicksand or Wet Clay

FIG. 38.

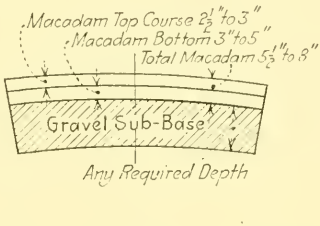


FIG. 39.

FIGS. 38 and 39.—Effect of type of base on thickness of macadam surface.

boulder or telford base immediately underlies the macadam, the thickness of the macadam can be reduced to 3½ to 5 in. as the boulder base has better supporting power than the gravel for direct concentrated loading. That is, the object of macadam cap over the boulder base is to smooth the road for the use of traffic.

The line of pressure distribution is about the same through boulder base or gravel with the evidence slightly in favor of the gravel.

The use of gravel for subbase does not increase the total necessary pavement depth but it does increase the necessary thickness of the true macadam type of surfacing (see Figs. 38 and 39).

For any depth up to 8 in., the true macadam top and bottom courses are generally selected. For greater depths, any combination can be used keeping the depth of the macadam capping to the minimum safe depth for the type of subbase used.

Recommended Depths.—From the foregoing theoretical and practical data, the following recommended depths are derived. Such recommendations are intended for use in localities subject to severe winters and

for the design loading outlined in Table 12, page 82. They are only intended as a guide to indicate the trend of design practice. There is no intention of creating the impression that they are necessarily the best solutions for all cases but they can be used with assurance of reasonable success in case local practice has not been crystalized by long experience.

TABLE 17.—RECOMMENDED TOTAL DEPTHS OF FLEXIBLE PAVEMENTS IN LOCALITIES SUBJECT TO SEVERE WINTERS (IN INCHES)

Class I Traffic (over 2,000 vehicles daily, 10-hr. count in summer)
(Macadam not usually economical on Class I roads)

Soil	Location of road		
	In cuts or on shallow fills less than 1 ft. deep	On intermediate fills 1 to 3 ft. deep	On high fills over 3 ft. deep
Coarse sand and fine gravel	9 to 10	9 to 10	9
Loams	10 to 14	10 to 12	10
Ordinary clays	15 to 21	12 to 16	11
Heavy clays and fine sands	22 to 30	14 to 18	13
Class II Traffic (800 to 2,000 vehicles daily, 10-hr. count in summer)			
Sand and gravel	8 to 9	8 to 9	8
Loams	9 to 12	9 to 11	9
Ordinary clays	12 to 18	11 to 15	10
Heavy clays and fine sands	18 to 28	13 to 16	12
Class III Traffic (300 to 800 vehicles daily, 10-hr. count in summer)			
Sand and gravel	7 to 8	7 to 8	7
Loams	8 to 10	8 to 9	8
Ordinary clays	12 to 16	9 to 14	9
Heavy clays and fine sands	18 to 24	12 to 15	11
Class IV Traffic (less than 300 vehicles daily)			
Sand and gravel	6 to 7	6 to 7	6
Loams	7 to 9	7 to 8	7
Ordinary clays	10 to 15	8 to 12	8
Heavy clays and fine sands	15 to 22	10 to 14	9

It can be seen from the foregoing discussion that while in a strict sense macadam pavement depth is not susceptible to true engineering

design, it is susceptible to a rational analysis which tends to produce better balanced results than the purely hit or miss methods that have been in more or less use for the past 15 years. *In the author's opinion, the flexible type of pavement is generally the most economical type for 90 per cent or more of the road mileage in most localities and for this reason rational design is essential.*

Asphaltic Concrete and Block Surfacings on Macadam Bases.—This type of road is a desirable design where an old firm well-consolidated macadam rood needs a better type of surface. *Asphaltic concrete or any high type block surface should never be laid on new macadam as it is impossible to get complete consolidation of macadam without the added help of traffic pounding.*

FIG. 40.—Successful asphaltic concrete (modified Topeka) surface on old solid telford stone base on a heavy traffic street in Rochester, N. Y. The surface has been down for 10 years and remarkably free from temperature cracks or other flaws.

Firm macadam bases having the thicknesses previously discussed make an ideal foundation for asphaltic concretes and block with mastic fillers as temperature cracks are largely eliminated. Temperature cracks are the main difficulty encountered where these pavements are laid on concrete foundations.

Figure 40 shows an asphaltic concrete surface laid on an old telford base on one of the heavy traffic streets of Rochester. This pavement is in better shape than any of the adjacent pavements with concrete bases. Figure 10, page 36, shows a rural asphaltic concrete surface on old firm macadam base. *The general conclusion to be drawn is that where an old firm macadam of adequate depth has been constructed in the past that it makes an excellent base for a higher type surfacing.* For the quick con-

struction of an asphalt or brick surface on a heavy traffic unimproved road, the concrete base is the most feasible design. It is well to bear in mind, however, that while from a practical standpoint the use of a concrete base on new grading is the best solution for quick results, expensive failures often result from the construction of concrete on new fills or over sewer trenches that have not had time to settle; it is desirable to wait at least a season after a road is graded before placing a rigid pavement. This delay is rarely possible but if it is feasible, the macadam-base type has the advantage as the macadam base gives good service to traffic while it is consolidating and eventually produces a more satisfactory base than concrete except for exceptionally heavy volume and unit traffic (Class I Roads). Where asphaltic concrete is used on top of macadam the depth of asphaltic surface can be considered as equivalent to an equal depth of macadam. On this basis Table 17 is directly available for computing required total depths.

Rigid Pavement Design.—Rigid pavements are more difficult to analyze for strength design than the macadam type but an approximation can be derived. The following discussion is not a scientific analysis in any sense of the word as this is impossible to achieve at the present stage of experimental knowledge. It is desirable however to develop empirical formulae which are based on available experimental data coordinated with actual traffic tests.

Considerable progress has been made in the last few years towards a fairly well-balanced design of strength. Investigations in regard to temperature warping, fatigue of materials, soil support, etc. have established fairly definite general principles which have modified the old style design to advantage. These modifications include reduction in unit width of monolithic type slabs, increase in the strength of the outer edge of narrow rural highway pavements and improvement in quality and manipulation of materials. Theory developed from experimental research seems to have been essentially verified by traffic tests and while there is still considerable range for judgment in assigning values to the various factors in the formulae there is no serious disagreement in regard to essentials. *A discussion of formulated design is given with the idea of bringing out the factors of the problem for the student rather than as providing hard and fast standards of designs.* As a matter of fact a careful analysis of any theoretical discussion of pavement design shows plainly that experience with actual traffic tests is the most reliable basis for action. Table 23, page 137, gives the summarized recommendations based on both theory and practice. This table is of definite practical value.

Design Fundamentals (Rigid Slabs).—As outlined on page 73 rigid pavements are designed to bridge over small areas where there is either partial or complete loss of soil support. If large areas of the subgrade

settle materially the pavement fails; it is necessary to provide enough slab strength to bridge all areas of poor soil support which ordinarily occur under the usual construction conditions but it is prohibitive in cost to design a pavement for exceptional areas of settlement.[1] It is, of course, impossible to determine exactly what size these commonly occurring weak areas will be and it is necessary to assume some maximum condition of loss of soil support for which provision will be made. The so-called corner load Formula developed in 1919 by the Illinois Highway Dept., Clifford Older, Chief Engineer, seems to afford a practical mathematical basis of comparison of slab strengths ordinarily needed to produce economical pavements which will not have too great percentages of weak areas. *This formula should, however, be used as an index of relative strength rather than as a basis of absolute strength as it eliminates soil support as a direct factor in the computations.*

Observed pavement failures indicate the predominance of corner area weakness. Recent experiment has determined that soil contact under corners and along the edges of slabs is quite commonly completely lost or at least reduced to negligible value. This condition is due to temperature warping, to compression of subgrade due to edge deflection of slabs under heavy truck traffic and to increase in the moisture content of the subgrade soil by ground water seepage and the seepage of surface water through cracks and down through ruts along the edge of the pavement.[2] The extent and frequency of serious loss of soil support can be reduced by narrowing the width of slabs, by constant sealing of surface cracks, by well constructed and maintained shoulders and by effective under drainage but even with the greatest care in these particulars soil support is unreliable at corners. These recognized conditions led to the development of the corner load formula. It is expressed as $d = \sqrt{\frac{JW}{S}}$ in which

d = Depth of slab in inches.
W = Design wheel load in pounds.
S = Maximum allowable design tension value in pounds per square inch.
J = Variable factor determined by load distribution and location of critical load.

Soil support is disregarded as a direct factor in the computations.

While all the factors W, S and J are more or less indefinite, actual road service tests are rapidly eliminating any wide range of uncertainty.

[1] Some efforts have been made to develop an economical design on the basis of pillar support extending below frost line. This basis of design simplifies the design stress problem but it is not likely that any system of bridge floor slab design can compete economically with a base partially in contact with the earth subgrade.

[2] Bates Experimental Road *Bulletins*, Illinois Dept. of Highways.

The formula can be used directly for most cases with good results but it has more real value as an index of relative strength than as a basis of design of absolute strength on account of complete disregard of soil support. The results obtained by the formula are susceptible to percentage modifications due to reasonable allowances for normal conditions of some soil support. Such modifications depend on direct traffic tests for normal conditions. The impossibility of exactly determining the value of soil support is the stumbling block in applying scientific design to any type of pavement, either rigid or flexible. The formula is developed as follows:

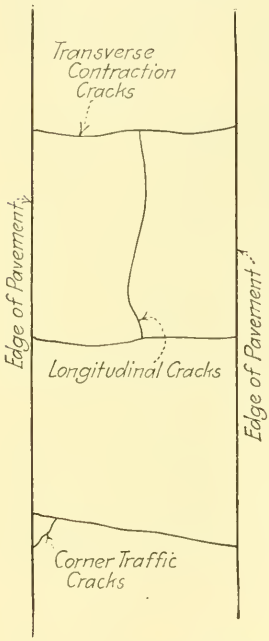


Fig. 41.—Typical cracks.

The Corner Load Formula.—Rigid pavements are considered as a series of slabs. This is essentially correct for most modern monolithic pavements are constructed with well-defined joints and most two-course pavements which may be originally constructed as a continuous slab are later broken up by temperature and traffic action into a series of slabs. Mr. Older is quoted as follows:

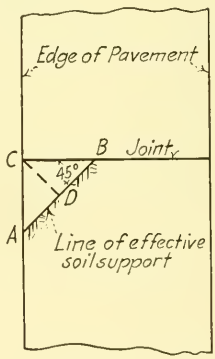


Fig. 41A.—Corner load formula diagram.

Corners Critical Points.—It may be safely stated that cracks and joints, *if properly cared for,* affect the life of a rigid slab only as they may affect its strength or load carrying capacity.

It is not necessary to apply mathematical calculations to develop the fact that a load applied near the center of a comparatively large unbroken pavement slab would produce much lower stresses therein than would be produced were the same load applied at or near the edge of the same slab. Further it is evident that a load applied at the edge of an unbroken slab would not produce stresses as great as those produced by the same load placed at a corner formed by cracks or joints. It is obvious that these are bending stresses which must be withstood by the resisting moment of the slab.

Regardless of the supporting capacity of the subgrade, it is the corners formed by intersection of cracks or joints with each other and with the edges of

the pavement that constitute the weak points of rigid slab pavements. On the Illinois roads which carry truck traffic many broken corners have been observed in all types of rigid pavements, and only in a single instance has a traffic break been observed that was not readily traceable to the piecemeal breaking down of corners or narrow strips formed by longitudinal cracks making acute angles with the edge of the slab. The exception was an asphalt top pavement on a 1:3:5 concrete base 4 in. thick at the sides and 5 in. thick in the center which broke into small pieces under excessive truck traffic. An examination of the base showed that its transverse strength had been exceeded even in the center of the slab. No concrete slab 6 in. or more in thickness has broken except at corners or except over trenches or other causes of localized settlement.

Until we are able to control completely the cracking of rigid slabs it seems obvious that we must design the entire slab to carry the imposed loads at the weak point—*the corners.*

This last paragraph of Mr. Older's statement must not be construed to mean that pavements must be of uniform thickness throughout as this would result in unbalanced and uneconomical design. That is, the location of corners (such as along the edge of the pavement as compared with interior corners) and other factors later discussed have considerable bearing on the stress produced by normal wheel loads. If due allowance is made for the location and special conditions of load application at different kinds of corners this test (corner resisting moment) can be used quite successfully in the design of pavement strength.

The relation of traffic load to necessary corner resisting moment of the slab is quite simple assuming complete loss of soil support for a small area under the corner, load applied at extreme corner, intersection angle of joints, sides and cracks 90°.

The resisting moment of the slab along the line AB (Fig. 41*A*)

$$= \frac{SI}{\frac{d}{2}} = \frac{Sbd^3}{6d} = \frac{Sbd^2}{6}$$

Where

S = allowable tensile stress in outer fiber.

I = moment of inertia of the section along line $AB = \frac{bd^3}{12}$

d = depth of slab in inches.

b = distance AB in inches.

The load moment is expressed as load (L) in pounds, times the moment arm CD in inches. At right-angle corners the distance CD is always $\frac{1}{2}$ of $AB = \left(\frac{b}{2}\right)$ no matter what distance CD becomes. This gives a constant relation between the load moment and resisting moment regardless of variations in the size of areas of no support under corners.

$$\text{Load Moment } (M) = \frac{Lb}{2}$$

The load moment and resisting moment must be the same where soil support is completely lost.

$$\frac{Lb}{2} = \frac{Sbd^2}{6}$$

$$d^2 = \frac{3L}{S}$$

$$d = \sqrt{\frac{3L}{S}}$$

For convenience this is modified to $d = \sqrt{\frac{JW}{S}}$ where W equals the design wheel load (discussed on page 82); J equals (3 $\times$ the decimal part of W which can be considered as applied at the extreme corner) and S equals the maximum allowable design tension value for the material or combination of materials making up the road slab.

Utilization of Corner Load Formula in Design.—The successful use of this formula depends on the determination of reasonable values for tensile strength of the slab (S), wheel load (W), load distribution at joints in conjunction with location of load (J) and soil support modifications which control the factor of safety of the finally adopted depth. A short discussion of each factor follows. They will then be assembled for the different types of pavement and a table prepared which shows roughly the effect of load or depth and compares the depths required for the different types of pavement under specified legal load limits.

Design Values for Tensile Strength (S).—Pavement slabs are constructed of plain concrete without any reinforcement, concrete containing small percentages of embedded steel; combinations of cement concrete and brick with a fairly firm bond (so called Monolithic Brick) and combinations of Bituminous Concrete or block surfaces on Cement Concrete bases with a well-defined plane of weakness between base and surface courses. All pavement slabs subject to bending stresses fail from tension weakness. It is well established that it is uneconomical and impracticable to attempt to reinforce thin pavement bases with enough steel to take full advantage of the compressive strength of concrete. The tensile resistance of concrete can be raised slightly for small areas such as corners by means of bar reinforcement. Construction imperfections in mix and materials can be equalized by light mesh which acts as a fibrous tie and the use of small amounts of steel in this way permits a raise in allowable design stress but if failure occurs it is always a tension failure. It is therefore only necessary to consider the safe tensile strength of the materials or combination of materials in computing slab strength.

In adopting values for tension to be used in the corner load formulae, it is desirable to use the highest reasonable value as there is no objection to a small percentage of pavement failure. The values given at the close of this portion of the discussion have been tentatively adopted as their

use in conjunction with the distribution factors and wheel loads recommended seem to result in pavement thicknesses which have proved to be adequate under tests of modern traffic. These values are somewhat higher than many authorities advise.

The discussion of design tension values is based on the Modulus of Rupture of Materials. The term Modulus of Rupture is defined as follows by Hool and Johnson:

> The transverse or beam strength of granular brittle materials like mortars and concretes is best expressed by the Modulus of Rupture. The modulus of rupture is the apparent stress in the extreme fiber of a transverse test specimen under the load which produces rupture. For specimens of rectangular section of breath b and depth d, loaded centrally on a span l, the breaking load being W, the modulus of rupture is computed by the formula
>
> $$\text{Modulus of Rupture} = \frac{3Wl}{2bd^2}$$
>
> The extreme fiber stress thus computed is not the actual fiber stress because the formula involves the inaccurate assumption that the material deforms elastically for all stresses up to rupture. The comparative relations between results are not affected by this inaccuracy of the formula, however, when the tests compared are made upon specimens of similar material, because the computed values of the modulus of rupture are very nearly proportional to the actual stresses.
>
> Since the extreme fiber stresses on the tension side and on the compression side of a beam of homogeneous material are equal, and the tensile strength of mortar or concrete is only a small fraction of the compressive strength, the transverse strength of mortar or concrete is almost wholly dependent upon the tensile strength. The modulus of rupture found in transverse tests will invariably be considerably in excess of the tensile strength, however, because the computed stress in the extreme fiber considerably exceeds the actual stress.

Modulus of Rupture of Plain Concrete.—For a number of years it has been quite well established that loads producing computed stresses exceeding 50 to 60 per cent of the modulus of rupture of plain concrete result in permanent deflections. Recent experiments by the Illinois Highway Department on the effect of repetition of load on rupture have shown that loads producing computed stresses of 37 per cent of the modulus of rupture can be repeated 1,000,000 times without causing failure; loads producing stresses of 53 per cent of the modulus of rupture were repeated from 40,000 to 200,000 times before rupture occurred; loads producing stresses of 70 per cent of the modulus of rupture broke the test piece after repetitions of from a few hundred to a few thousand applications. To prevent rupture due to unlimited repetition of load, it is therefore desirable to adopt a design stress of about 45 per cent of the Modulus of Rupture.

The modulus of rupture of concrete pavements or bases has considerable range in value depending on the mix, age of concrete and perfection

of construction operations. It would be impracticable and uneconomical to attempt to use a design tension value which would prevent occasional failure of fresh concrete under repeated heavy loading.

New pavements are generally opened to traffic in 14 to 28 days after construction. It is necessary to provide enough strength at this time to prevent corner breaks due to the loading produced by normal traffic. The pavement must be able to handle immediately a few applications of the maximum permissible wheel load but it is not rational to make the pavement strong enough at this stage to stand repeated rapid applications of the maximum legal load nor is it likely that this condition will occur except under very unusual conditions.

The pavement must be strong enough when first opened to permit continual application of the loads produced by the usual vehicle but these loads are far below the legal maximum. The maximum wheel pressure permitted by law is only produced by a very small percentage of the vehicles operating on the usual road. These vehicles in passing over the pavement only apply their load at critical corner points to a very small percentage of the slab corners. It is not likely that a single slab corner has the maximum legal load applied to the extreme corner with greater frequency than say $\frac{1}{100}$ of 1 per cent of the number of vehicles using the road. The concrete rapidly gains strength with age so that if a design tension value is adopted high enough to prevent rupture at the 28-day age for maximum load without considering the effects of repetition, the probabilities are all in favor that it will gain strength fast enough to take care of the maximum loads as they occur. We, therefore, recommend a value of about 65 per cent modulus of rupture for 28-day concrete in conjunction with the maximum legal wheel load. This means that the stress produced by the ordinary light vehicles is less than 50 per cent of the modulus of rupture at 28-day age and can be repeated indefinitely even at that stage. Within 6 months or a year the concrete will probably gain sufficient additional strength to stand indefinite repetitions of the maximum legal load. If some corners break during the first few months, they can be repaired under the item of minor repair. For exceptional roads carrying a large volume of heavy trucking, it is, perhaps, desirable to reduce the design tension values somewhat or to insist on longer aging before the road is opened to traffic.

The following tabulation shows the approximate ratio of the design stress recommended for 1:1½:3 concrete to the modulus of rupture at 28 days, 6 months and a year.

Recommended design tension value	Approximate ratio of recommended stress to modulus of rupture		
	28 days	6 months	1 year
400 lb. per square inch, per cent	65%	50%	45%

The ratio of Modulus of Rupture to compressive strength (28-day) determined for ordinary road concrete mixes on 6-× 12-in. cylinders is approximately 23 per cent (see Table 18).

The tabulation below gives the recommended values for (*S*) Tension to be used in the corner load formula for plain concrete pavement and base design:

ADOPTED VALUES (*S*) DESIGN TENSILE STRENGTH VALUE FOR PLAIN CONCRETE PAVEMENTS AND PAVEMENT BASES

1:1½:3 mix	400
1:2 :4 mix	360
1:2½:5 mix	320
1:3 :6[1] mix	280

[1] Recent tests (1921) by the Bureau of Public Roads indicate that the strength of 1:3:6 concrete tested for beam action is about 80 per cent of the strength of 1:1½:3 mix while the ratio of direct compressive strength of these mixes is 1 to 2. The adopted values use a ratio of 70 per cent for beam action.

Tables 18, 18A and 18B give reliable test values of the Modulus of Rupture and serve as the supporting data for the recommended values.

Table 19 compares direct tension with Modulus of Rupture.

Appendix D gives Modulus of Rupture Bates Road Tests for actual failures under truck traffic. (See page 603.)

TABLE 18.—EFFECT OF SIZE AND GRADING OF AGGREGATE AND AGE OF CONCRETE

Bulletin 11, Lewis Institute Chicago. Prof. Duff A. Abrams.

Aggregates: sand from Janesville, Wis., and pebbles from Elgin, Ill. Aggregates of *different size* were obtained by separating sand and pebbles into various sizes and recombining as shown by sieve analyses in Table 11 and Fig. 1. *Different gradings* of aggregates were produced by mixing sand (0 to No. 4) and pebbles (No. 4 to 1½ in.) in different proportions.

Mix, 1 : 4 by volume. Relative consistency, 1.10.

Specimens tested damp.

Each value is the average of 5 tests made on different days.

Ref. No.	Aggregate: Size	Aggregate: Fineness modulus	Water-ratio of concrete	Modulus of rupture of beams, lb. per per sq. in.: 7 d.	28 d.	3 m.	1 y.	Compressive strength 6- by 12-in. cylinder, lb. per sq. in.: 7 d.	28 d.	3 m.	1 y.	Modulus of rupture, per cent of compression: 7 d.	28 d.	3 m.	1 y.
				Effect of Size of Aggregate.											
36	0–16	1.95	1.29	95	160	255	340	270	620	1,190	1,600	35.2	25.8	21.5	21.2
37	0–8	2.17	1.25	95	195	320	370	360	850	1,470	1,860	26.4	23.0	21.8	19.9
38	0–4	2.45	1.20	125	250	370	425	430	1,010	1,620	2,100	29.4	24.8	22.8	20.2
39	0–⅜	4.00	0.98	290	455	595	640	1,040	2,110	2,930	4,490	27.9	21.6	20.3	14.3
40	0–¾	5.00	0.87	365	560	730	775	1,290	2,650	3,650	4,890	28.3	21.2	20.0	15.9
41	**0–1½**	**5.65**	**0.82**	**420**	**550**[1]	**810**	**880**	**1,410**	**2,580**[1]	**3,590**	**5,000**	**29.8**	**21.3**	**22.6**	**17.6**
			Aver.	230	360	510	570	800	1,640	2,410	3,320	29.5	22.9	21.5	18.2
				Effect of Grading of Aggregate.											
29	0–1½	3.00	1.11	165	255	410	450	620	1,290	1,640	2,330	26.6	19.8	25.0	19.3
30	0–1½	4.00	0.98	230	390	505	570	950	2,000	2,550	3,230	24.2	19.5	19.8	17.7
31	0–1½	4.50	0.93	285	485	610	645	1,090	2,190	2,750	3,830	26.2	22.2	22.2	16.9
32	0–1½	5.00	0.87	325	505	660	710	1,160	2,410	3,580	4,510	28.0	21.0	18.4	15.8
33	0–1½	5.25	0.85	365	555	735	820	1,320	2,940	3,810	5,340	27.7	18.9	19.3	15.4
41	**0–1½**	**5.65**	**0.82**	**420**	**550**[1]	**810**	**880**	**1,410**	**2,580**[1]	**3,590**	**5,000**	**29.8**	**21.3**	**22.6**	**17.6**
34	0–1½	6.00	0.78	405	600	735	825	1,300	2,250	3,310	4,400	31.2	26.7	22.2	18.8
35	0–1½	6.25	0.77	385	590	730	865	1,140	1,990	2,840	4,080	33.8	29.6	25.7	21.2
			Aver.	320	490	650	720	1,120	2,210	3,010	4,090	28.4	22.4	21.9	17.8

NOTE.—**Ordinary Concrete Pavement mixture shown in black faced type (Reference No. 41).**

[1] Average of 25-beam tests and 115 cylinder tests.

TABLE 18A.—TRANSVERSE STRENGTH OF MORTARS AND CONCRETES

Tests of William B. Fuller

Proportions by weight, cement, sand, stone	Proportions by volume, cement, sand, stone	28-day age. Modulus of rupture (lb. per. sq. in.)		
		Maximum	Minimum	Average of 6
1:1: 2	1:1.17: 2.06	798	646	710
1:1: 3	1:1.17: 3.09	732	573	656
1:2: 4	1:2.34: 4.12	480	399	439
1:2: 5	1:2.34: 5.17	413	349	380
1:3: 5	1:3.51: 5.17	308	262	285
1:3: 6	1:3.51: 6.21	246	213	226
1:4: 8	1:4.68: 8.25	158	156	157
1:6:10	1:7.02:10.34	91	87	89

TABLE 18B.—RESISTANCES OF PAVEMENT SECTIONS TESTED AS BEAMS UNDER STATIC LOADS (AGE OF SPECIMENS 1 YEAR)

Tests by Bureau of Public Roads

No. of beam	Description				Total load at center, pounds	Modulus of rupture lb. per sq. in.
	Thickness of base, inches	Mix	Thickness of surface, inches	Type of surface		
1	...	1–1½–3 concrete	4	.....	430	302
2	...	do	4	.....	1,330	812
3	...	do	4	.....	980	620
4	...	do	6	.....	1,080	292
5	...	do	6	.....	2,880	773
6	...	do	8	.....	3,950	595
7	...	do	8	.....	3,250	498
8	...	do	8	.....	3,350	512
9	...	do	10	.....	6,110	583
10	...	do	10	.....	5,285	508
11	...	do	10	.....	5,410	520
12	...	1–3–6 concrete	3	.....	520	525
13	...	do	4	.....	710	500
14	...	do	4	.....	710	511
15	...	do	4	.....	640	454
16	...	do	6	.....	1,520	450
17	...	do	6	.....	1,655	485
18	...	.....	6	.....	1,330	399
19	...	.....	6	.....	1,690	491
20	...	.....	6	.....	1,560	459
21	2	1–3–6 concrete	3½	Vertical fiber brick, grout filler	1,340	433
22	2	do	3½	do	1,410	497
23	2	do	3½	do	1,410	485
24	2	do	4	Repressed brick, grout filler	1,850	572
25	2	do	4	do	1,410	412
26	2	do	4	do	1,520	453
27	2	do	4	Wire cut lug brick, grout filler	1,940	504
28	2	do	4	do	1,250	364
29	3	do	3	do	800	245
30	3	do	3	do	1,810	538
31	3	do	3	do	1,170	306
32	3	do	4	do	1,910	319
33	3	do	3½	Vertical fiber brick, grout filler	1,590	362
34	4	do	3½	do	1,650	284
35	4	do	3½	do	2,040	344

TABLE 18B.—RESISTANCES OF PAVEMENT SECTIONS TESTED AS BEAMS UNDER STATIC LOADS. (*Continued*)

No. of beam	Thickness of base, inches	Mix	Description		Total load at center, pounds	Modulus of rupture lb per sq. in.
			Thickness of surface, inches	Type of surface		
36	4	do	3½	do	3,185	463
37	4	do	4	Repressed brick, grout filler	1,910	319
38	4	do	4	do	1,460	254
39	4	do	4	Wire cut lug brick, grout filler	2,420	421
40	4	do	4	do	2,110	304
41	4	do	4	do	2,480	403
42	5	do	3	do	2,040	340
43	5	do	3	do	2,740	444
44	6	do	4	Repressed brick, grout filler	3,510	400
45	6	do	4	do	3,060	353
46	6	do	4	do	4,210	427
47	6	do	4	Wire cut lug brick, tar-mastic filler	1,340	132
48	6	do	4	do	1,910	184
49	6	do	4	Wire cut lug brick, tar-mastic filler screening cushion	1,655	154
50	6	do	4	Wire cut lug brick, tar filler, screening cushion	825	95
51	6	do	4	Wire cut lug brick, grout filler	2,810	269
52	6	do	4	do	2,610	305
53	6	do	4	do	2,480	306
54	6	do	4	do	1,850	351
55	7	do	3	do	4,840	485
56	7	do	3	do	2,925	358
57	...	.....	3½	Vertical fiber brick, grout filler	700	574
58	...	.....	3½	do	950	991
59	...	.....	4	Repressed brick, grout filler	1,080	715
60	...	.....	4	do	955	640
61	...	.....	4	Wire cut lug brick, grout filler	955	623
62	...	.....	4	do	1,020	679
63	...	.....	4	do	1,280	829
64	...	.....	4	do	900	608
65	...	.....	4	do	1,120	754

Table 19 compares the value of Direct Tensile strength tests with Modulus of Rupture.

TABLE 19

Mix	Ultimate tensile strength, pounds per square inch	Modulus of rupture, pounds per square inch
1:1½:3	300 to 450	500 to 700
1:2 :4	250 to 350	400 to 600
1:2½:5	200 to 300	350 to 450
1:3 :6	150 to 250	250 to 400

Modulus of Rupture (Reinforced Concrete).—The proper use of steel in road design is discussed in Chap. III. It is sufficient to note at this point that light mesh weighing from 0.25 to 0.65 lb. per square foot has been found useful in raising the average strength of the concrete

throughout the slab and that corner bar reinforcement of sufficient area to raise materially the modulus of rupture at such points is common practice.

Experimental data on the effect of small percentages of steel on modulus of rupture is very meager. Experiments by the Bureau of Mines, Lewis Institute (Prof. Abrams) and at Cornell give some basis for assumptions in this matter but the experiments do not cover a very wide range of size and spacing of steel bars or wire mesh and are not conclusive as yet (see Table 20A and 20B). The results indicate that light bar reinforcement having an effective area of less than $\frac{2}{10}$ of 1 per cent has practically no effect in increasing the modulus of rupture of the beam. We, however, know from experience that light mesh weighing about 0.25 to 0.4 lb. per square foot and having an effective area of about $\frac{5}{100}$ of 1 per cent apparently has considerable effect in reducing interior cracks though not much effect in reducing corner cracks. This is probably due to its action as a fibrous tie in equalizing construction imperfections. The use of even the light mesh seems to warrant a slight increase in the value of (S) for infrequent internal crack corners held in close contact by longitudinal side bar reinforcement. The use of corner bar

TABLE 20A.—EFFECT OF NUMBER OF STEEL REINFORCING BARS

Bulletin 11, Lewis Institute Chicago. Prof. Duff. A. Abrams (1922).

Beams: Depth, 7 in.; width, 10 in.; span, 36 in.

Longitudinal reinforcing bars were spaced equally across the width and 1 in. from the bottom of the beam. The total depth of beams varied from 6.9 to 7.1 in.

Mix, 1 : 4 by volume. Aggregate: sand and pebbles graded 0 to 1½ in.

Relative consistency of concrete, 1.10; water-ratio, 0.82.

Age at test, 28 days.

Specimens tested damp.

Each value is the average of 5 tests made on different days.

Compressive strength of 6- by 12-in. concrete cylinders (average of 115 tests) was 2,580 lb. per sq. in.

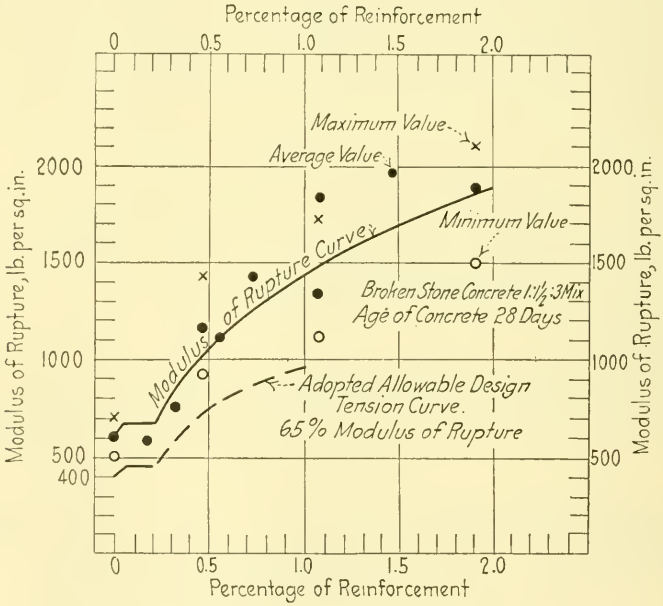
Reference number	Number of ¾-in. round steel bars	Percentage of steel	Total load on beam, pounds	Computed stresses, lb. per sq. in.					Type of beam failure
				Tension in steel	Compression in top fiber	Bond	Shearing unit stress	Modulus of rupture	
7, 8	0	None	7,870[2]	.....	.....	...	70	550[2]	Tension
59	1	0.18	7,850	73,000[1]	1,470[1]	570	70	560[1]	Tension
60	2	0.36	10,390	49,400[1]	1,460[1]	380	90	730[1]	Tension
61	3	0.54	15,010	49,100[1]	1,850[1]	380	140	1,085[1]	Tension
62	4	0.72	19,640	48,900[1]	2,190[1]	380	180	1,435[1]	Diagonal shear
63	6	1.09	25,820	43,800[1]	2,160[1]	340	240	1,885[1]	Diagonal shear
64	8	1.46	28,060	36,800[1]	2,530[1]	290	270	1,990[1]	Diagonal shear

[1] Tension in concrete not considered in computing steel stress. Steel not considered as taking stress in computing modulus of rupture.

[2] Average of 25-beam tests.

TABLE 20B.—RECORD OF TESTS AT CORNELL UNIVERSITY ON REINFORCED CONCRETE BEAMS 5- × 7-IN. SPAN, 4.0-FT. CENTRAL LOAD (AGE 28 DAYS)

Proportions by volume	Per cent of reinforcement	Max.	Min.	Average
Gravel Concrete				
1:5	0.47	887	722	844 (4 tests)
1:5	1.07	1,262	826	1,032 (4 tests)
1:5	1.89	1,300	1,020	1,175 (4 tests)
Crushed Stone Concrete				
1:1½:3½	0.47	1,430	916	1,159 (6 tests)
1:1½:3½	1.07	1,720	1,123	1,344 (6 tests)
1:1½:3½	1.89	2,100	1,500	1,880 (6 tests)



Percentage Reinforcement	Adopted Allowable Tension Value (S) 1:1½:3 Concrete
0.0	400 lbs. per sq. in.
0.1	460 " " " ".
0.2	470 " " " "
0.3	580 " " " "
0.4	670 " " " "
0.5	760 " " " "

FIG. 42.—Effect of steel reinforcement on modulus of rupture of concrete.

reinforcement having an effective area of 0.2 per cent or more has a decided value as determined by both experiment and practice. The effect of different percentages of reinforcement on modulus of rupture and the tentative recommended values for (S) tension are shown in Fig. 42. These values are based on Table 20.

Even with considerable more experimental data, the effect of steel in actual design would be open to uncertainty for the following reasons. Road slabs are so thin that even small variations in location of the steel upsets its theoretical effect as regards tension. Even with the most intelligent labor and inspection considerable variation occurs so that the net practical value of steel as a tension reinforcement is open to considerable uncertainty. For the thicker slabs 7 to 8 in. reasonably close assumptions can be made. These depths give bars some chance to actually work. For slabs less than 7 in. deep steel is of little value in raising tension. In these slabs its value is confined to equalization and contact uses as later discussed. For the purposes of this discussion the relation between depth of slab and theoretical tensile effectiveness of steel is assumed as follows:

Depth of slab, inches	Assumed effectiveness (S)	
	Mesh reinforcement, per cent theoretical[1]	Corner bars, per cent theoretical
7½ or more	100	100
7	100	90
6½	80	60
6	50	0

[1] Light mesh reinforcement can be safely placed nearer the surface of the concrete than ½- or ⅝-in. bar reinforcement.

The actual value of steel is really more a matter of cut and try than it is of theoretical design but this data serves as a basis for judgment.

Wheel Load Factor (W).—The wheel loads were discussed on page 82. The reader is referred back to that data which recommended the following design loads for Class I and II Traffic. These recommended design wheel loads include an allowance for impact and apply to districts in which the gross vehicle load is limited to 28,000 lb.

Figures 47 to 51, which show graphically the theoretical depths obtained from the use of the corner load formula, consider a range of design wheel load from 6,000 to 20,000. As a rule 9,000 lb. is the least design load applicable to actual traffic conditions and 16,000 lb. the maximum. There are unusual cases, however, where 20,000-lb. load does occur today (1922) (see Appendix C, Massachusetts Traffic Report). Such loads violate legal statutes and their occurrence shows the necessity

for police regulation unless adequate depth provision is made for their occurrence.

TABLE OF RECOMMENDED DESIGN WHEEL LOADS FOR DISTRICTS HAVING A 28,000-LB. LEGAL MAXIMUM LIMIT

Type of pavement	Design wheel[1] load (W), pounds
Asphaltic concrete on cement concrete base	12,000
Asphalt block on cement concrete base	14,000
Plain or reinforced cement concrete	14,000
Brick (cement grout) concrete base	14,000
Monolithic brick	14,000
Brick (Bituminous filled) bit sand cushion	14,000
Brick (Bituminous filled) cement sand cushion	15,000
Stone block	16,000

[1] The differences are due to variation in impact allowance for different surfaces.

Location and Distribution of Load at Joints (J).—Both the location and distribution of loads affect the value of J (effective load applied at extreme corner of slab).

Critical Location of Load.—There are two general classes of slab corners, exterior and interior (Fig. 43). Wheel loads can be applied very close to the extreme corner along the outer edges of pavements with earth shoulders. It is impossible to apply the full wheel load at interior corners closer than about 6 in. from the extreme point. This means that it is not possible for the load moment to be as great at interior corners as along the outer edge of pavements having earth shoulders. This condition in conjunction with other factors later discussed indicates in a general way that Monolithic Rural Highway Pavements constructed without raised curb edges should be designed stronger along the outer edge than along central joints. This conclusion is borne out by observed failures fewer of which occur along central joints than along the outer edge. Recent designs recognize this fact by specially strong outer edge design (see Chap. III). City Street Pavements with raised curbs have only one class of corner namely; Interior Classification.

The exact effect of this difference in location of load on values for J is not known but a rough approximation can be made. Corner cracks rarely start at more than 30 in. to 36 in. away from the corner point and generally at less distance. If we assume 36 in. as an extreme distance a difference of 6 in. in moment arm would reduce the load moment about 15 per cent for interior corners which is a conservative allowance. The finally adopted values for J may well be about 15 to 20 per cent less for interior corners than for exterior corners. Distribution of load at

joints is however the main factor in determining reasonable values for J.

Distribution of Wheel Loads at Joints.—The distribution of load between adjacent slabs at joints and cracks is a variable and indefinite factor. In monolithic pavements it depends largely on the degree of contact which is much better during the day than at night and better in the summer than in the winter. The use of steel tie members in concrete increases the contact, at least temporarily (see Chap. III). For pavements with separate concrete bases and top surfacing courses like asphaltic concrete, semi-monolithic brick, etc., it is certain that the dis-

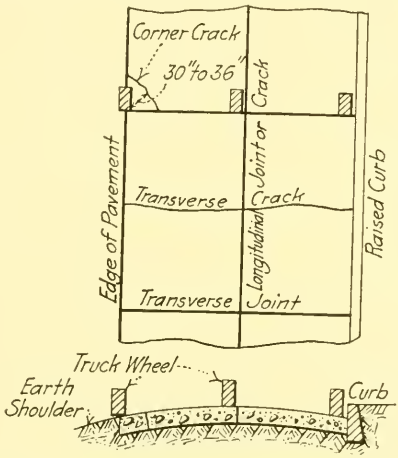


FIG. 43.—Location of critical wheel loads at internal and external corners.

tribution of load over base cracks is much better than for the monolithic slab type. Most of the experimental data deals with distribution at joints in monolithic concrete and brick. These types will be given first consideration and the values adopted can then be modified for the other types by data which compares this factor in an indirect manner.

Monolithic Slab Joint Distribution.—Table 21 taken from an article by H. F. Clemmer of the Illinois Department of Highways and C. A. Hogentogler, U. S. Bureau of Public Roads is probably as reliable data as can be obtained at present (1922). This table shows a wide range in values.

It is possible that under favorable conditions the load may be equally distributed between adjacent slabs but this is not likely to be the case for many cases at cracks in the plain concrete slab type or at expansion joints filled with bitumen. For the most adverse conditions of contact, a single corner may carry the entire wheel load. At expansion joints it is not unlikely that this condition occurs at intervals but as the factor of safety of the formula is to be provided by the soil contact factor it is

not advisable to assume the highest possible value for J. Values are derived as follows for Plain Concrete Pavements:

As defined on page 106, $J = 3 \times$ the effective part of the wheel load actually applied at the extreme corner. The effective part is made up of the part of wheel load W carried by a single corner modified for location of this load. The extreme possible range for exterior corners ranges from $1.0W$ to $0.5W$ applied at the extreme point. This would give a possible range of value for J at exterior corners of

Wheel load carried by single corner	Value of J (exterior corners)
$0.5W$	1.5
$0.6W$	1.8
$0.7W$	2.1
$0.8W$	2.4
$0.9W$	2.7
$1.0W$	3.0

The value of 2.6 is considered safe and reasonable for exterior corner condition in Plain Concrete Slab Design. Interior corner value is reduced 15 per cent giving a value of 2.2 recommended.

In pavements containing embedded steel the distribution at expansion joints is the same as for the plain concrete type. Where joints or cracks not subject to expansion movement are held in contact by tie bars or dowels the distribution is materially increased. Some designers advocate values for J based on a 50 per cent distribution but this seems rather optimistic. We recommend a value for exterior corners based on $0.7W$ which equals 2.1 reduced to 1.7 for interior corners.

The adoption of values for J as applied to two course pavements such as asphaltic concrete, block pavements etc., depends on indirect comparison of the action of these pavements with the monolithic type under traffic and experimental beam tests. These values for two course pavements are still in the speculative stage but if they are adjusted to produce rational results in conjunction with the values for W and S which are fairly certain there is some justification for the use of the corner load formula in connection with the design of two course pavements.

Any top course adds something to the resistance of the concrete base by its effect on wheel impact, increase in the reliability of load distribution over base cracks, reduction in probability of load being applied at the extreme corner of the base slab and reduction in probability of surface water seepage through cracks to the underlying subgrade. Of these considerations J is only affected by distribution and location of load.

TABLE 21.—OBSERVED AND COMPUTED DEFLECTIONS OF SLAB CORNERS ADJACENT TO JOINTS

Section			Oct. night obs. deflection				Oct. day obs. deflection				Inc. per cent dist. day and night	Dec. total movement day and night	Computed equal deflections for both slabs at joint					
													Rear wheel			Front wheel		
No.	thick, inches	Kind	Load on near side	Load on far side	Per cent load carried across joint	Total movement of corners	Load on near side	Load on far side	Per cent load carried across joint	Total movement of corners			Night	Day	Diff.	Night	Day	Diff.
40	9	Conc.	0.081	0.024	**13.0**	.....	0.040	0.019	**35.0**	.....	22.0							
40	9	Conc.	0.066	0.012	**26.0**	0.111	0.042	0.021	**30.0**	0.042	4.0	0.069	0.046	0.031	0.015	0.016	0.008	0.008
40	9	Conc.	0.041	0.040	**49.0**	.....	0.035	0.035	**50.0**	.....	1.0							
39	8	Mono.	0.040	0.039	**49.0**	0.002	0.035	0.035	**50.0**	0.0	1.0	0.002	0.040	0.035	0.005	0.009	0.006	0.003
42	8	Conc.	0.078	0.037	**43.0**	.....	0.030	0.030	**50.0**	.....	7.0							
43	7	Conc.	0.050	0.030	**26.0**	0.061	0.030	0.030	**50.0**	0.0	24.0	0.061	0.047	0.030	0.017	0.011	0.007	0.004
63B	7	Conc.	0.075	0.026	**15.0**	.....	0.055	0.026	**18.0**	.....	3.0							
63A	7	Conc.	0.070	0.015	**29.0**	0.104	0.047	0.014	**38.0**	0.062	9.0	0.042	0.046	0.038	0.008	0.016	0.008	0.008
44	7	Conc.	0.094	0.004	**11.0**	.....	0.060	0.011	**18.0**	.....	7.0							
45	6	Conc.	0.106	0.009	**5.0**	0.187	0.076	0.016	**15.0**	0.109	10.0	0.079	0.057	0.040	0.017	0.016	0.007	0.009
38	7	Mono.	0.045	0.045	**50.0**	.....	0.037	0.037	**50.0**	.....	0.0							
37	6	Mono.	0.045	0.045	**50.0**	0.00	0.037	0.037	**50.0**	0.00	0.0	0.00	0.045	0.037	0.008	0.012	0.008	0.004
48	6	Conc.	0.085	0.035	**47.0**	.....	0.048	0.043	**41.0**	.....	6.0							
47	6	Conc.	0.092	0.060	**20.0**	0.082	0.044	0.038	**46.0**	0.011	26.0	0.071	0.070	0.044	0.026	0.025	0.011	0.014
51	6	Conc.	0.114	0.095	**20.0**	.....	0.076	0.059	**28.0**	.....	8.0							
50	6	Conc.	0.105	0.063	**33.0**	0.061	0.079	0.050	**44.0**	0.046	11.0	0.015	0.098	0.066	0.432	0.028	0.018	0.010
52	6	Conc.	0.094	0.053	**15.0**	.....	0.086	0.050	**49.0**	.....	35.0							
51	6	Conc.	0.101	0.027	**46.0**	0.115	0.073	0.008	**46.0**	0.101	0.0	0.012	0.078	0.057	0.031	0.024	0.015	0.009

NOTE.—Equal deflections of both corners at joints indicates perfect contact or 50 per cent distribution.

The recommended values are based on the consensus of opinion of engineers in western New York and on experimental results recorded in Appendix D (Bates Road) and the following quotation from an article by C. A. Hogentogler, U. S. Bureau of Public Roads, Nov. 1921, summarizing recent Arlington experimental tests:

The monolithic brick-concrete slabs in most cases showed less resistance than the 1:1½:3 concrete slabs of the same depth. Failure of the former seemed to result from the shearing of the brick top from the concrete base before full resistance of the monolithic was developed. This allowed the specimens to develop at most only the sum of the resistance of the two parts. The monolithic sections tested as beams under static loads failed in the same way, but the resistance of the beams seemed to be slightly in excess of the sum of the top and bottom strengths, while the slab resistances compared favorably with the sum of the resistances of the two parts. This would indicate that higher shearing stresses are developed by impact than by equivalent static loads.

With possibly one exception (slab 106) the grouted-brick tops with sand-cement cushions on concrete bases showed less resistance than the monolithic sections.

Grout-filled brick tops with sand and screening cushions on concrete bases showed slightly greater resistances than would be expected from the bases alone.

Grout-brick surfaces compared favorably with 1:1½:3 slabs of equal thickness, while grouted-brick beams showed resistances in excess of those offered by equal thicknesses of 1:1½:3 concrete.

As would be expected the beam strengths of the bases were not much increased by bitumen-filled brick tops.

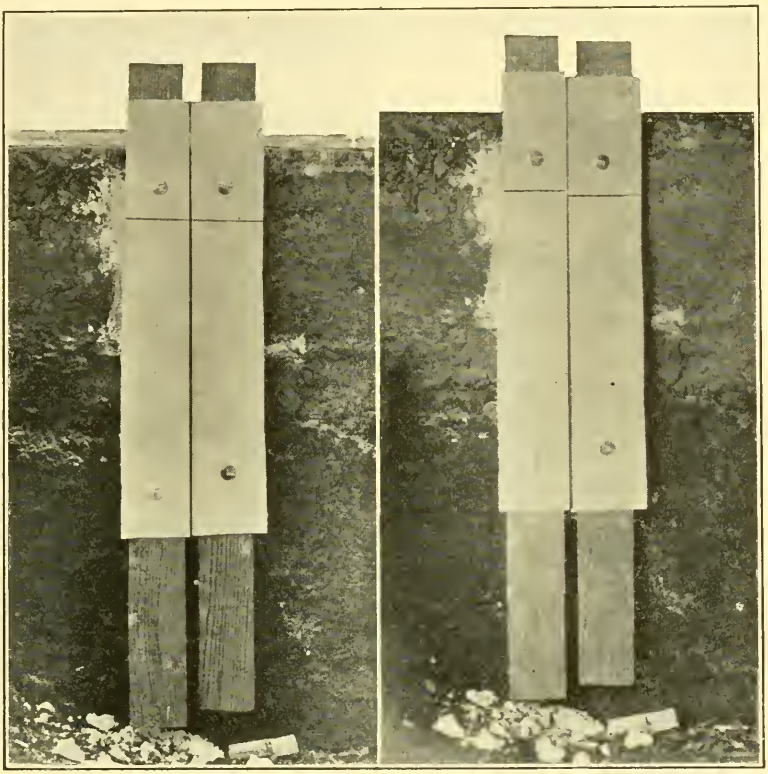
Recommended Values (J) Two Course Pavements

Type of pavement	Value of (J) interior corner classification
Asphaltic concrete pavements	1.2 to 1.3
Block pavements (bituminous joints)	1.2 to 1.3
Block pavements (cement grout joints)	0.8 to 0.9

Recommended Values (J) Monolithic Pavements

Type of pavement	Value (J) exterior corners	Value (J) interior corners
Plain concrete	2.6	2.2
Monolithic brick	2.6	2.2
Reinforced concrete		
At expansion joints	2.6	2.2
At cracks or contraction joints with bar ties	2.1	1.7

Soil Support (Percentage Modification Factor P).—As this is the most indefinite element of the problem it seems desirable to adopt values which are on the safe side and in this way provide the necessary factor of safety for the formula. The depths directly computed by the formula $d = \sqrt{\frac{JW}{S}}$ assume complete loss of soil support. If soil support is given some consideration in design it is recognized by an arbitrary percentage modification of depths and the percentage used must agree with the



A *B*

FIGS. 44, *A* and *B*.—Photographic evidence of loss of soil support due to temperature warping of monolithic concrete pavement slab. (*Courtesy of Illinois Dept. of Highways, Bates Road Tests.*)

observed action of pavements under traffic tests on different subsoils. For practical application to design the formula may be written as $d = P\sqrt{\frac{JW}{S}}$, where P represents the soil-support factor.

Engineers differ considerably in regard to the allowable reduction in depth due to partial soil support; they are however practically unanimous in agreement that some allowance should be made for the factor particularly where a rigid pavement is laid on top of an old firm macadam road

in reconstruction programs. Where really unstable subgrades such as muck or quicksand are encountered it is necessary to stabilize the subgrade by means of gravel or cinder subbase well underdrained before the rigid pavement can be laid with any degree of success. The value assigned to (P) has an important effect on the practical value of the formula.

If the complete loss of soil support were a common continuous occurrence on the ordinary subgrade soils such as loams and the stiffer clays we would have had a larger percentage of failure on some of our old thin rigid pavements than has actually been the case. This indicates that these soils usually give some support. On the other hand there have been enough observed failures to indicate that it is not safe to assume much support from these soils under adverse conditions. The following short quotation from *Bulletin* 18, Bates Experimental Road, gives experimental data in connection with the loss of soil support due to temperature warping.

> The curling of the edges of a concrete slab 18 ft. wide may be sufficient to render the most perfect of subgrades ineffective under the edges of the slab. This can be readily determined without the aid of accurate measuring devices. To visualize this condition the photographs shown on page 121 were made:

This data indicates that monolithic pavements having slab widths of 10 ft. or less and the usual two course pavements having widths of 20 ft. or less generally receive some benefit from soil support at edges and corners. Experience indicates that if we adopt values for (P) of 1.1 for wide monolithic slabs and values of 0.8 to 1.0 for narrow slabs and two course pavements that the results are safe. The following values for P depending on the character of the subgrade seem to be about as good a guess as can be hazarded at present (1923):

Subgrade conditions	Type of pavement	Adopted formula
Ordinary loams and clays	Wide monolithic slabs.	$d = 1.1\sqrt{\frac{JW}{S}}$
	Narrow slabs or two course pavements	$d = 1.0\sqrt{\frac{JW}{S}}$
Coarse gravels or macadams	Wide monolithic	$d = 1.0\sqrt{\frac{JW}{S}}$
	Narrow slabs or two course pavements	$d = 0.9\sqrt{\frac{JW}{S}}$
Quicksand and muck	Wide monolithic	Subbase $+ d = 1.1\sqrt{\frac{JW}{S}}$
	Narrow monolithic or two course pavements	Subbase $+ d = 1.0\sqrt{\frac{JW}{S}}$

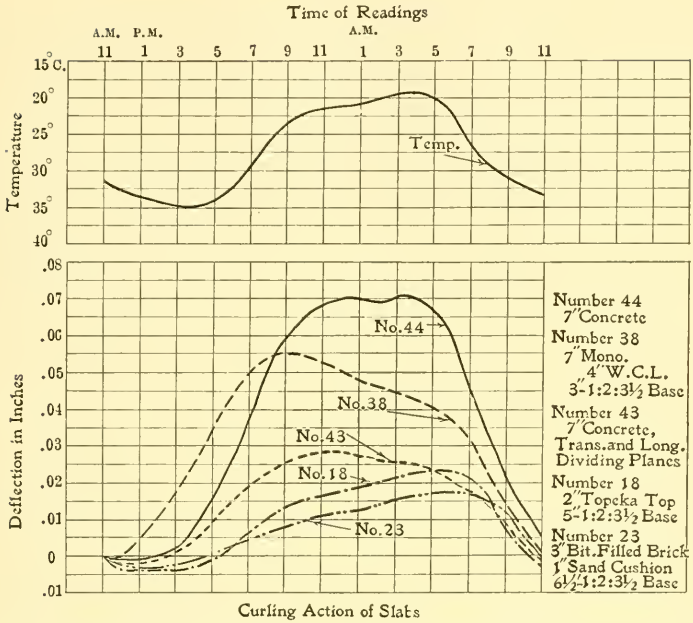


FIG. 45.—Bates road experiments on rigid slab warping due to temperature.

Summary of Discussion of Factors.—The preceding discussion outlines the wide range of possible values for each of the factors in the formula

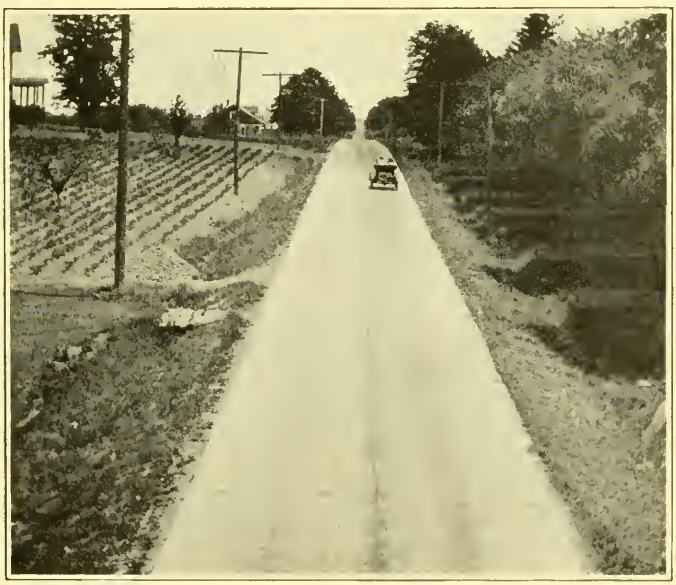


FIG. 46.—Central longitudinal joint construction 18 ft. width cement concrete pavement constructed half at a time.

$d = P\sqrt{\frac{JW}{S}}$. There is enough variation in these values to give some theoretical justification for practically any depth in common use. The range in values shows that proper design depends very largely on the judgment of the designer. The student may well bear in mind however, that many engineering formulae such as sewer runoff, etc. which have been found very useful in practice, are susceptible to the same variation in final results and that the values of such formulae have been gradually increased by modifying experimental factor values to agree with actual service tests. A formula of this nature is very useful in coordinating the experience of a large number of different men working on the same general problem as it affords a convenient means of expressing their experience in mathematical form.

The practical use of the corner load formula is illustrated in the following pages for each common type by showing the range in possible values, giving a recommended set of values for normal conditions and computing the depths required for different wheel load limits. These results are compared with ordinary practice. It is not likely that the recommended depths can be safely changed more than 5 to 10 per cent for normal conditions. For special traffic conditions changes can be made in the factor values but it is not desirable to use a combination of all high or all low values.

Plain Concrete Pavements.—Chapter III discusses joint details, richness of mix, etc. Design is based as a rule on a system of longitudinal and transverse joints which divide the pavement into slabs of from 8 to 12 ft. width and from 30 to 40 ft. length, which usually controls the natural tendency of the pavement to crack under temperature and frost action. That is, some intermediate cracking will occur but the intersection of joints and infrequent internal cracking are at approximately 90°-angles. Richness of mix varies from 1:2:4 on unimportant roads to 1:1½:3 on main heavy traffic roads. Factor values and resultant depths are indicated as follows for the formula $d = P\sqrt{\frac{JW}{S}}$.

Recommended Factor Values for Class I and II Roads in Districts Permitting a 28,000-lb. Gross Vehicle Load

Design wheel load, including impact (W), pounds	14,000
Load distribution (J) exterior corners	2.6
Load distribution (J) interior corners	2.2
Design tensile stress (S) 1:1½:3 mix, pounds per square inch	400
Design tensile stress (S) 1:2:4 mix, pounds per square inch	360
Soil support factor (P), ordinary soils	1.0
Soil support factor (P), gravel and macadam	0.9

This results in the following recommended theoretical depths for 1:1½:3 mix (28,000 lb. vehicle load).

ORDINARY FOUNDATION SOILS

Outer edge of pavement $d = 1.0\sqrt{\frac{2.6(14{,}000)}{400}} = 9.5$ in.

Interior areas of pavement $d = 1.0\sqrt{\frac{2.2(14{,}000)}{4}} = 8.8$ in.[1]

GRAVEL OR MACADAM FOUNDATION

Outer edge of pavement $d = 0.9\sqrt{\frac{2.6(14{,}000)}{400}} = 8.5$ in.

Interior areas of pavement $d = 0.9\sqrt{\frac{2.2(14{,}000)}{4}} = 7.9$ in.[1]

Variation in depth due to changes in the design wheel load are shown in Fig. 47 below.

Ordinary practice in plain concrete road design uses average depths of from 5½ to 11 in. (see Table 22, page 136, and Chap. III for details).

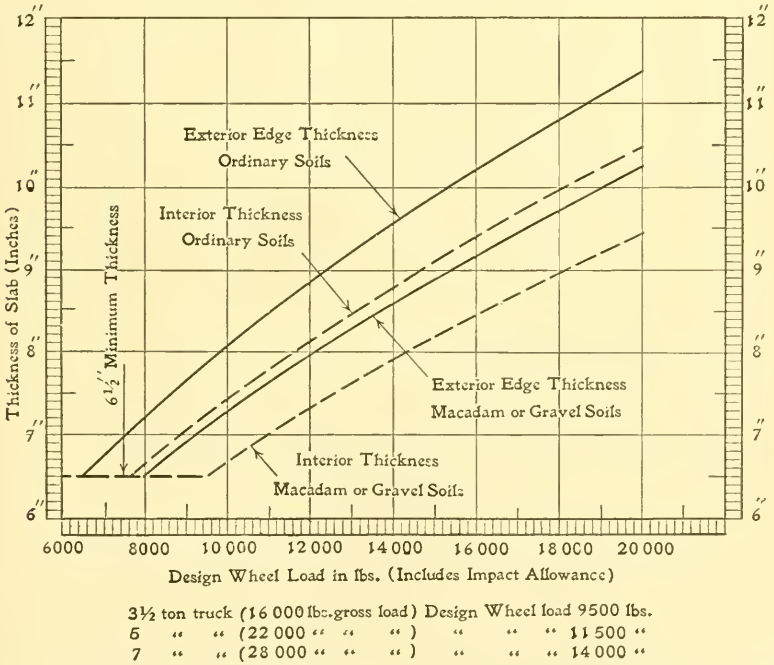


FIG. 47.—Theoretical thickness plain concrete slabs 8 to 12 ft. wide 1: 1½: 3 mix (crushing strength 28-day age 3,000 to 4,000 lb. per square inch).

[1] Interior area classification applies to total width of curbed streets.

Where pavements are constructed over new trenches (culverts or sewers) which will surely settle the slab depths at such localized places are designed on the principle of bridge slab depths with extra bottom reinforcement (see page 129).

While a considerable milage of plain concrete pavements have been constructed and are serving moderately well the tendency in design is to use some steel as considered in the next section.

Reinforced Concrete Pavements.—These pavements are designed on the same general arrangement of joints as the plain concrete except that the length of slab is usually somewhat greater (40 ft. being a common length).[1] The following theoretical depths consider steel 100 per cent effective for tie purposes but of little effect in increasing tensile strength for slabs less than 6½ in. thick. The depth of the pavement is computed on the basis of corners at intermediate cracks between expansion joints where good contact is fairly certain. Corners at expansion joints are given the same thickness as close contact corners and the necessary additional bar reinforcement is provided to take care of the extra stress due to poorer joint distribution.

Recommended Factor Values. Class I and II Roads in Districts Permitting a 28,000-lb. Gross Vehicle Load

Design wheel load including impact (W), pounds		14,000
Load distribution (J) exterior corners		2.1
Load distribution (J) interior corners		1.7
Load distribution (J) exterior expansion joints		2.6
Load distribution (J) interior expansion joints		2.2
Design tensile strength for all parts of slab except at expansion joint corners assuming 0.3 to 0.4 lb. mesh reinforcement per square foot and side tie bars.	1:1½:3 mix, pounds	450
	1:2 :4 mix, pounds	420

If mesh is omitted and tie bars alone used the tension value (S) is recommended at 400 lb. per square inch (1:1½:3 mix) and 360 lb. (1:24 mix) using J values for tight contact (see Fig. 48A).

Soil support factor (P), ordinary soils	1.0
Soil support factor (P), gravel or macadam	0.9

This results in the following recommended depths and corner reinforcement for 1:1½:3 mix. (28,000 lb. gross vehicle load).

Ordinary Foundation Soils

Outer edge of pavement $d = 1.0\sqrt{\frac{2.1(14{,}000)}{450}} = 8.1$ in.

Interior areas of pavement $d = 1.0\sqrt{\frac{1.7(14{,}000)}{450}} = 7.3$ in.[2]

[1] On account of future surfacings of bituminous concrete 33 ft. is probably a better spacing to reduce localized movement.

[2] Interior area classification applies to total width of curbed streets. Design tensile stress at expansion joint corners.

Design tensile stress at expansion joint corners.

Outside corner $S = \frac{JW}{d^2} = \frac{2.6(14{,}000)}{8.1^2} = 550$ lb.

Inside corner $= \frac{2.2(14{,}000)}{7.3^2} = 580$ lb.

Figure 42, page 114, indicates that a design stress of 580 lb. requires approximately 0.3 of 1 per cent area of reinforcement. This applies for the sectional area of the slab back about 30 in. from the extreme corner. Size and spacing of corner bars are based on this data.

Gravel or Macadam Foundation

Outer edge of pavement $d = 0.9\sqrt{\frac{2.1(14{,}000)}{450}} = 7.3$ in.

Interior areas of pavement $d = 0.9\sqrt{\frac{1.7(14{,}000)}{450}} = 6.6$ in.[1]

Outside corners $S = 0.8\frac{JW}{d^2} = 0.8\frac{2.6(14{,}000)}{7.3^2} = 550$ lb.

Interior corners $= 0.8\frac{2.2(14{,}000)}{6.6^2} = 570$ lb

} Expansion joints

Requires 0.3 of 1 per cent reinforcement.

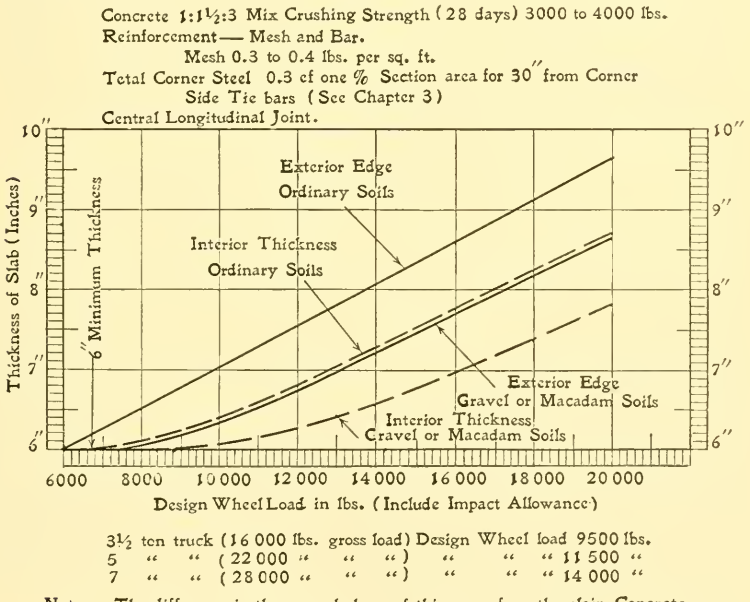

Concrete 1:1½:3 Mix Crushing Strength (28 days) 3000 to 4000 lbs.
Reinforcement— Mesh and Bar.
Mesh 0.3 to 0.4 lbs. per sq. ft.
Total Corner Steel 0.3 of one % Section area for 30" from Corner
Side Tie bars (See Chapter 3)
Central Longitudinal Joint.
Thickness of Slab (Inches)
10"
9"
8"
7"
6"
Minimum Thickness
Exterior Edge
Ordinary Soils
Interior Thickness
Ordinary Soils
Exterior Edge
Gravel or Macadam Soils
Interior Thickness
Gravel or Macadam Soils
6000
8000
10 000
12 000
14 000
16 000
18 000
20 000
Design Wheel Load in lbs. (Include Impact Allowance)
3½ ton truck (16 000 lbs. gross load) Design Wheel load 9500 lbs.
5 " " (22 000 " " ") " " " 11 500 "
7 " " (28 000 " " ") " " " 14 000 "
Note: The difference in the general shape of this curve from the plain Concrete curve is due to the decreasing effectiveness of steel for slabs less than 7" thick

Fig. 48.—Theoretical thickness reinforced cement concrete. 1: 1½: 3 mix, mesh and bar reinforcement, transverse and longitudinal joints.

[1] Interior area classification applies to total width of curbed streets. Design tensile stress at expansion joint corners.

Theoretical variation in depth due to changes in the design wheel load are shown in Figs. 48 and 48A for 1 : 1½ : 3 mix with different kinds of reinforcement.

Effect of Steel on Depth.—A comparison of Figs. 47, 48 and 48A indicates that the use of tie and corner bars reduces the required thick-

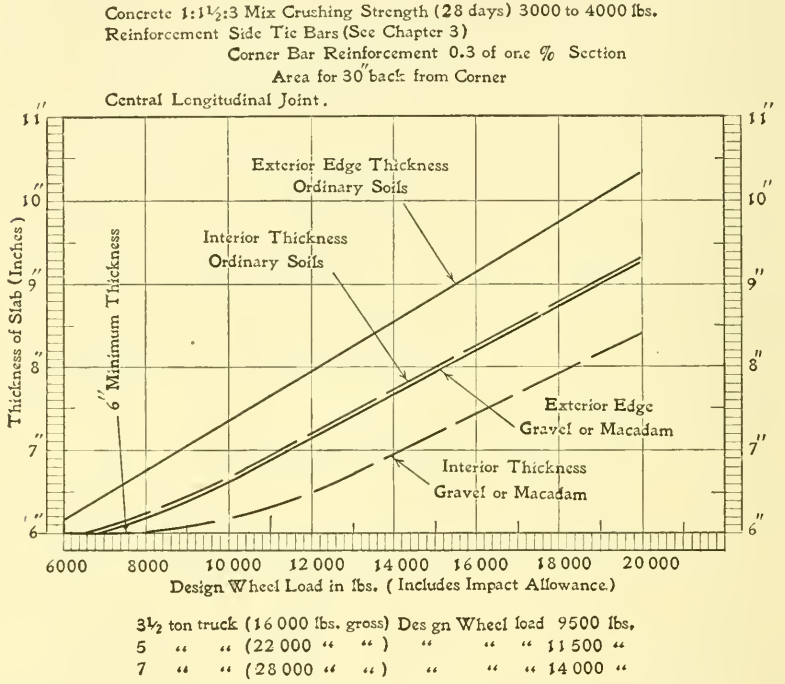


FIG. 48A.—Theoretical thickness reinforced concrete 1: 1½: 3 mix, side tie bar and corner bar reinforcement, transverse and longitudinal joints.

ness of plain concrete slabs about an inch and that the use of mesh, tie bars and corner bars reduces the required depth of concrete about one and a half inches. This applies only for load conditions requiring depths of plain concrete of 8 in. or more. Expressed in terms of money, tie and corner bars reduce the cost of concrete about $0.04 a square foot (1922 cost conditions) and tie, corner bars and mesh reduce the cost of the concrete about $0.06 per square foot. The cost of the steel used as reinforcement should not exceed these limits. The cost of steel reinforcement is usually less than this amount which indicates that the use of steel is economically desirable.

Ordinary practice in reinforced concrete pavement design uses average depths of from 5 to 8 in. For relative depths of sides and edges and reinforcement details see Chap. III.

Depth over Trenches.—Where pavements are constructed over new trenches (culverts or sewers) which will surely settle, the slab depths at such localized places should be thickened and given additional bottom

reinforcement to conform with bridge floor slab practice. The following table indicates in a general way the maximum width of trench it is safe to span with standard road slabs of 1:1½:3 mix for different legal load limits based on formula (safe span) $= \frac{32S(d)^2}{W}$

Maximum load	Approximate maximum allowable trench width safe to span without additional thickening (1:1½:3 Mix) in feet			
	Column headings are depths of standard pavement slabs			
	6 in.	7 in.	8 in.	9 in.
3½-ton truck (16,000 lb. gross)	4.0	5.5	7.5	9.5
5 -ton truck (22,000 lb. gross)	3.5	5.0	6.5	8.0
7 -ton truck (28,000 lb. gross)	3.0	4.5	5.5	6.5

NOTE.—These widths assume beam action. That is, joints must not be constructed directly over a trench.

Trend in Design.—A comparison of the following table of Current Practice depths with the preceding discussion of recommended theoreti-

TABLE OF RANGE IN DEPTH OF CONCRETE PAVEMENTS. CURRENT PRACTICE, 1919–1922 IN INCHES

State	Plain concrete	Reinforced concrete
Arizona	5½ to 9	.....
California	6	5 to 6
Connecticut	6 to 9	.....
Illinois	.. ....	6 to 9
Indiana	7 to 8	7 to 8
Maryland	6½ to 8	.....
Massachusetts	.....	7½ to 8
Minnesota	.....	7½
New Jersey (1922)	8	8
New Jersey (1919)	6 to 10½	.....
New York	.....	6 to 7
Pennsylvania	7 to 9	6 to 8
Rhode Island	6 to 8	6 to 8
Washington[1]	6 to 11[1]	6 to 11[1]
West Virginia	6 to 9	.....
Wisconsin	7 to 8	.....

[1] State of Washington, 11-in. depth for short distances where settlement may occur.

NOTE.—The preceding theoretical analysis indicated the following depths as reasonable for a 28,000-lb. gross vehicle load. Ordinary foundation soils.

Plain concrete (1:1½:3 Mix)..... 8¾ to 9¾ in.
Reinforced concrete (1:1½:3 Mix)..... 7½ to 8½ in.

cal depths shows that with the exception of a few of the states, the maximum thickness in common use is somewhat less than the theoretical depths developed for a 28,000 lb. gross vehicle limit.

These theoretical depths are based on the maximum statutory load adopted in a number of the thickly settled states as it is believed that loading on main roads will tend to increase to the limit permitted by law. As previously discussed the rigid type of pavement is rarely economical on moderate or light traffic roads so the theoretical depths have been developed to represent Class I Traffic requirements. The states using depths as developed by these formulae are generally thickly settled with large cities and a heavy volume of commercial trucking on the main intercity routes. The author believes that a rigid pavement is not usually justified unless such conditions prevail but a great many localities are building lighter concrete roads for lighter traffic. If the designer is willing to recognize that he is taking a chance and considers the concrete pavement as a temporary expedient with the idea of capping it in a short time with some standard renewable surface, it may be justifiable to reduce the depth to that required for two course pavement bases. Under this line of reasoning the following minimum depths have some justification on the basis that the proposed future surfacing will raise the strength of the finally completed pavement up to that required for a 28,000-lb. gross vehicle load.

Plain Concrete—	1:1½:3 Mix	6½ in.
	1:2 :4 Mix	7 in.
Reinforced Concrete—	1:1½:3 Mix	6 in.
	1:2 :4 Mix	6½ in.

It however seems undesirable to carry this idea too far as it tends to discredit this type of pavement which is a very useful and economical type if properly designed for roads carrying from 2,000 to 6,000 vehicles daily (see Chaps. III and IV).

Bituminous Concrete Surface on Cement Concrete Base.—Cement concrete bases for these pavements are usually constructed as a continuous slab without any special provision for expansion or contraction. These bases crack with more or less regularity transversely across the pavement at intervals of 30 to 60 ft. and more infrequently in a longitudinal line near the center of the pavement and roughly parallel with the edges. That is, the action of the elements combined with traffic produce a series of slabs of varying sizes and shapes. Cracks in the asphaltic concrete surface often develop directly over the base crack but do not always show through to the surface which depends largely on the width of the base crack. Wide base cracks are not so frequent for the lean concretes as for the rich concretes because the coefficient of expansion is considerably less for a 1:3:6 than it is for a 1:2:4 mix (see page 307, Chap. III) and the lean bases generally develop transverse cracks at

shorter intervals due to less tensile strength. On account of this tendency of rich mixes to aggravate surface cracks in the overlying asphaltic surfaces most engineers advocate a base mix of from 1:3:6 to 1:2½:5 either one of which is a good practical mix as regards requisite resistance to moisture absorption and practical construction manipulation.

Pavements of this type on rural highways are generally constructed with an integral concrete edging to hold the edge of the mix from side displacement. This extra depth of concrete along the edge is usually considered to give the necessary extra strength of edge as compared with Interior Corner conditions. That is the base depth is made uniform and based on the interior corner classification where integral concrete edging is used. Where no edging is used the outer edge should be strengthened by any simple method, either extra edge depth or raised curbing.

In designing base depth for this type of pavement it is not permissible to figure on future strengthening. Adequate base strength must be provided as future renewals of worn-out asphaltic concrete surfaces remove the old surface course and replace with fresh mix. That is, resurfacing adds nothing to the final strength of this type of pavement.

The asphaltic surface wearing course varies as a rule from 2 in. without a binder course to 3 in. including a binder course. These depths are the result of experience and represent what appear to be feasible depths considering construction and maintenance problems. The variation in depth of asphalt surfaces as between 2 or 3 in. has little effect on the pavement base depth.

Recommended Factor Values for Class I and II Roads in Districts Permitting a 28,000-Lb. Gross Vehicle Load

Design wheel load, including impact (W), pounds	12,000
Load distribution factor (J) interior corners	1.3
Design tensile stress plain concrete base:	
1:3:6 mix	280 lb. per square inch
1:2½: 5 mix	320 lb. per square inch
1:2:4 mix	360 lb. per square inch
Soil support factor (P), ordinary soils	1.0
Soil support factor (P), gravel and macadam	0.9

These values result in the following recommended base depths for (28,000-lb. gross vehicle load). See Fig. 49 for more complete graphic results for different mixes and different design loads.

Ordinary Foundation Soils

1:2½:5 mix

$$\text{Depth of base } d = 1.0\sqrt{\frac{1.3(12{,}000)}{320}} = 7 \text{ in.}$$

Gravel and Macadam Subsoils

$$\text{Depth of base } d = 0.9\sqrt{\frac{1.3(12{,}000)}{320}} = 6.3 \text{ in.}$$

A few examples of ordinary practice in base depths are given as follows. Table 22, page 136, shows recent city street practice on heavy traffic streets.

Illinois (rural highways)	7 in.	(1:2 :3½ mix)
Pennsylvania (rural highways)	6 in.	(1:2½:5 mix)
New Jersey (rural highways)	6 in.	(1:3 :5 mix)
New York (rural highways)	5 in.	(1:2½:5 mix)
New York City (business streets)	9 in.	(1:2½:5 mix)

Depth over Trenches.—Increase in base depth applies as discussed page 128. For 7-ton truck loading it is probably desirable to increase for a 6-in. standard base of 1:3:6 concrete for trenches over 3 ft. wide. For a 7-in. depth of base where the trench width exceeds about 3.5 to 4 ft.

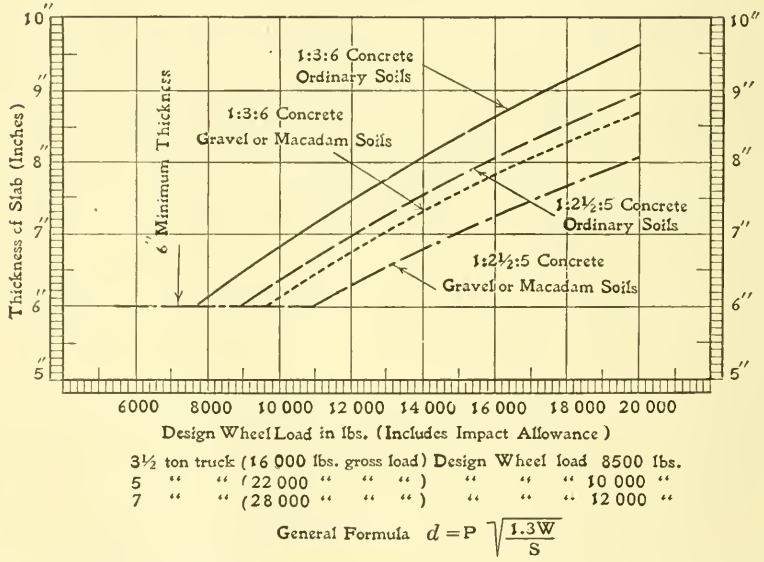

Thickness of Slab (Inches)
10″
9″
8″
7″
6″
5″
6″ Minimum Thickness
1:3:6 Concrete Ordinary Soils
1:3:6 Concrete Gravel or Macadam Soils
1:2½:5 Concrete Ordinary Soils
1:2½:5 Concrete Gravel or Macadam Soils
6000 8000 10 000 12 000 14 000 16 000 18 000 20 000
Design Wheel Load in lbs. (Includes Impact Allowance)
3½ ton truck (16 000 lbs. gross load) Design Wheel load 8500 lbs.
5 " " (22 000 " " ") " " " 10 000 "
7 " " (28 000 " " ") " " " 12 000 "
General Formula $d = P\sqrt{\frac{1.3W}{S}}$

Fig. 49.—Theoretical depth of cement concrete bases under bituminous concrete surfaces.

Brick, Stone Block, Etc., with Mastic Filler on Sand or Cement Sand Cushion and Concrete Base.—This design is rarely used on rural roads as it is an expensive type. The advantage of the mastic filler lies in the prevention of surface cracks. The prevention of these cracks on the score of better appearance of the pavement is important in cities but of secondary importance on rural highways. The disadvantage of the mastic filler lies in the loss of cantilever beam strength in the surface course and the production of more impact as the road serves traffic. It is not likely that the increase in impact is balanced by the cushion depth under the brick. It is certain that the base cannot be reduced in thick-

ness below that required for sheet asphalt and the probabilities are that a slight increase is logical. Formula $d = \sqrt{\frac{1.3W}{S}}$ with the additional impact allowance (page 116) seems to be about as good a guess as we can make on the basis of comparative action under traffic tests. This is perhaps a little ultra conservative.

For depths in use see Table 22, page 136, and Table 23, page 137.

Figure 50 illustrates graphically the results obtained by applying this formula.

Grouted Brick, Stone Block, Etc., on Cement Sand Cushion and Concrete Bases.—These types have the advantage of considerable beam strength in the surface layer as well as the base beam strength; according to the Office of Public Roads' tests previously quoted, they apparently do not as a rule develop as much beam strength as the monolithic form of brick pavement but the difference is slight. The evidence of actual pavements indicates that they give satisfactory service with bases somewhat less in depths than the asphaltic concrete tops type. Personally, the author believes that the semi-monolithic type will work satisfactorily under a design based on the depth of base $= \sqrt{\frac{0.9W}{S}}$; this is a rational modification of the asphaltic type formula as the grouted surface slab certainly adds more strength to the pavement than an asphaltic top and by beam action gives a wider distribution of load over base cracks and corners. As these formulae are intended to give relatively correct results and as experimental results are meager, this form will be tentatively adopted. It can be seen that the application of the corner load formula to this type is a speculative proposition.

The base under this formula becomes for loam and clay soils (28,000-lb. gross vehicle load).

$$1:2:4 \text{ mix} \quad \sqrt{\frac{12{,}600}{360}} = 6 \text{ in.}$$

$$1:2\tfrac{1}{2}:5 \text{ mix} \quad \sqrt{\frac{12{,}600}{320}} = 6.3 \text{ in.}$$

$$1:3:6 \text{ mix} \quad \sqrt{\frac{12{,}600}{275}} = 6.8 \text{ in.}$$

On gravel or old macadam subsoils the depths can be safely reduced ½ to ¾ in. but should under no circumstances of either load or soil be reduced below a 5-in. minimum. Figure No. 51 illustrates graphically the results of applying this formula.

Monolithic Brick Pavement Slabs.—This type has the same general characteristics as the monolithic plain concrete as far as impact and load

distribution at cracks are concerned. The difference between these two types lies in the fact that the plain concrete pavement is a true monolith and the combination of brick and concrete introduces a plane of weakness

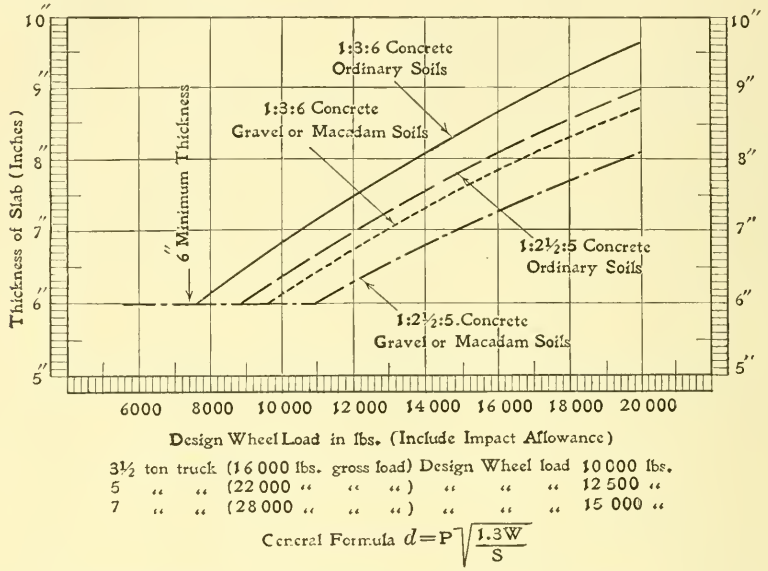

Thickness of Slab (Inches)
10″
9″
8″
7″
6″
5″
6″ Minimum Thickness
1:3:6 Concrete Ordinary Soils
1:3:6 Concrete Gravel or Macadam Soils
1:2½:5 Concrete Ordinary Soils
1:2½:5 Concrete Gravel or Macadam Soils
6000 8000 10 000 12 000 14 000 16 000 18 000 20 000
Design Wheel Load in lbs. (Include Impact Allowance)
3½ ton truck (16 000 lbs. gross load) Design Wheel load 10 000 lbs.
5 " " (22 000 " " ") " " " 12 500 "
7 " " (28 000 " " ") " " " 15 000 "
General Formula $d = P\sqrt{\frac{1.3W}{S}}$

FIG. 50.—Theoretical depth of cement concrete base under brick surface (mastic filler cement sand cushion).

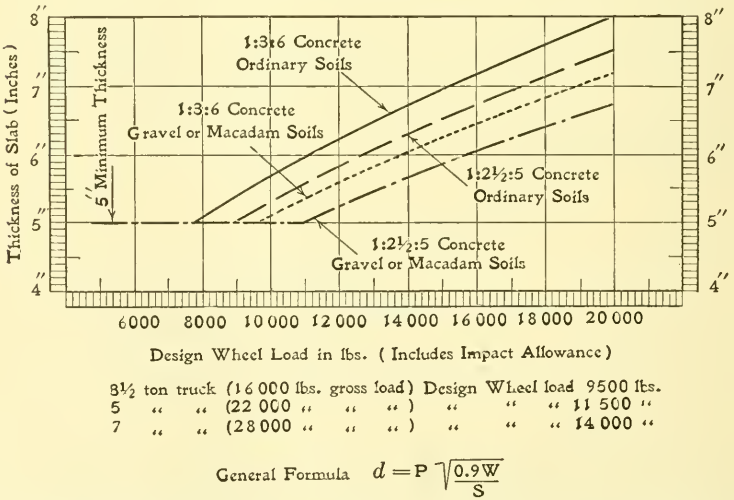

Thickness of Slab (Inches)
8″
7″
6″
5″
4″
5″ Minimum Thickness
1:3:6 Concrete Ordinary Soils
1:3:6 Concrete Gravel or Macadam Soils
1:2½:5 Concrete Ordinary Soils
1:2½:5 Concrete Gravel or Macadam Soils
6000 8000 10 000 12 000 14 000 16 000 18 000 20 000
Design Wheel Load in lbs. (Includes Impact Allowance)
8½ ton truck (16 000 lbs. gross load) Design Wheel load 9500 lbs.
5 " " (22 000 " " ") " " " 11 500 "
7 " " (28 000 " " ") " " " 14 000 "
General Formula $d = P\sqrt{\frac{0.9W}{S}}$

FIG. 51.—Theoretical depth of cement concrete bases under 4-in. brick surface (cement grout joints, cement sand cushion).

between the surface and bottom layers. The Bureau of Public Roads' experiments indicated that the beam strength of the so-called monolithic

brick pavement slabs was somewhat greater than the sum of the resisting moments of the upper and lower layers considered separately; values of modulus of rupture for well-grouted brick surfacing slabs as determined by the Bureau of Public Roads range from 600 to 1,000 lb. (see Table 18B, page 111). With this data, it is possible to make a speculative approximation of comparative strength depth. On page 125 the average depth of plain concrete 1 : 1½ : 3 mix using a tensile strength of 400 lb. per square inch was figured as 9.2 in. for a design load of 14,000 lb.

The resisting moment of this beam per foot of width is approximately 67,000 in.-lb. We will assume that 75 per cent of this must be handled by the sum of the resisting moments of the base and top considered separately, 50,000 in.-lb. Assume a working stress of 600 lb. for the brick top. A 4-in. brick slab has a resisting moment per foot width of 19,200 in.-lb. This leaves 31,000 in.-lb. for the base to handle.

Expressed as a formula, the depth of concrete base $= \sqrt{\frac{1.8W - 9{,}600}{S}}$ for loam and clay soils. On gravel or old macadam the depth can be reduced about an inch but under no circumstances of load or soil should a depth of less than 4 in. be used.

Depth of top	Average depth of concrete base, inches	Total depth of pavement, inches
4-in. brick top	(1:1½:3 mix) 6.3	10.2
	(1:2:4) 6.7	10.6

A few examples of current practice in monolithic brick construction follow: Monolithic brick construction is not in much favor in the northern states on account of cracking due to frost action and slab warping. Central longitudinal joints are not generally used on this type.

	Top, inches	Base, inches	Total, inches
Illinois	4	(1:2:3½ mix)	8
Indiana	4	4	8

Current Practice (Two Course Pavements).—Table 22 records current practice (1922) in two course pavement construction on heavy traffic city streets.

TABLE 22.—CURRENT PRACTICE IN DEPTH OF CONCRETE BASE UNDER PAVEMENTS ON HEAVY TRAFFIC CITY STREETS (1922)

City	Type of surface				Remarks
	Asphaltic concrete on concrete base, inches	Brick or stone block cement grout filler, inches	Brick or stone block mastic filler, inches	Concrete, inches	
Cleveland, Ohio.....	8	6	7		Tendency towards 7 in. to 8 in. except for grout filled block.
Detroit, Mich.....	8	8	8		
Chicago, Ill.....	8	8	8		This is recommended future practice.
Philadelphia, Pa.....	6	6	6		
Indianapolis, Ind....	6	6	6	.....	Gravel subsoil.
Baltimore, Md.....	6 to 8	6 to 8	6 to 8	.....	8 in. on poor soil.
New Orleans, La.....	6	6	6		
Boston, Mass.....	6	6	6	.....	Has been satisfactory.
Portland, Oregon....	6	6	6	6 to 10	

Effect of Statuatory Load Limit on Thickness of Rigid Pavements and Concrete Pavement Bases.—Table 23 gives a quick means of comparing the effect of load limit on rural pavement design. The black-faced type indicates the recommended depths for a statuatory gross vehicle limitation of 28,000 lb. which seems to be gaining favor as a practical basis of traffic regulation for the main roads. The depths given approximate equal strength for the different types and can be used as the basis for comparative estimates of cost. The determination of the effect of statuatory load and equal strength for different types are the main practical advantages of the foregoing analysis.

Cost Estimates.—The design of thickness governs the quantities to be used in comparative estimates of cost. The unit prices assigned to the various types depend on the materials available.

Local Materials.—Rational and economic design depends on the investigation for local material. Careless work in this particular results in specifying impracticable or needlessly expensive sources of supply for materials and often in the selection of an unreasonable type of construction. A careless estimate of the quantity of available local material also causes trouble during construction by a shortage in supply.

It is important not only to determine the amount of local material but also its character as for example a local gravel may be suitable for a first-class bottom for macadam construction but not suitable for a concrete pavement, or it may be suitable for a concrete paving base but not for a concrete road taking the traffic directly. A local hard sandstone may be

TABLE 23.—COMPARISON OF RECOMMENDED THEORETICAL DEPTHS OF CEMENT CONCRETE BASES FOR DIFFERENT PAVEMENTS UNDER DIFFERENT MAXIMUM LOADS ON DIFFERENT SOILS

(In Inches)

NOTE.—The last column gives prevailing practice in base depth for each type (1919 to 1922).

Pavement	Recommended depths of cement concrete bases based on modified corner load formula $d = P\sqrt{\frac{JW}{S}}$						Current practice 1919–1923, inches
	3½-ton truck 16,000-lb. gross load		5-ton truck 22,000-lb. gross load		7-ton truck 28,000-lb. gross load		
	Ordinary subsoils, inches	Gravel or macadam, inches	Ordinary subsoils, inches	Gravel or macadam, inches	Ordinary subsoils, inches	Gravel or macadam, subsoils, inches	
Plain concrete: (1:1½:3 mix)	7.2 & 7.8	6.5 & 7.0	7.9 & 8.8	7.2 & 8.0	**8.7 & 9.7**	**8.0 & 8.8**	6 to 10
Plain concrete: (1:2:4 mix)	7.6 & 8.2	6.9 & 7.4	8.4 & 9.2	7.6 & 8.3	**9.2 & 10.0**	**8.4 & 9.1**	
Reinforced concrete (mesh and bar): Central longitudinal joint (1:1½:3 mix)	6.3 & 6.9	6.0 & 6.4	6.7 & 7.5	6.2 & 6.8	**7.3 & 8.2**	**6.5 & 7.3**	
Reinforced concrete (corner and exterior tie bars only): Central longitudinal joint 1:1½:3 mix	6.5 & 7.0	6.0 & 6.4	7.0 & 7 8	6.3 & 7.1	**7.7 & 8.5**	**7.0 & 7.7**	5 to 9
1:2:4 mix	6.9 & 7.4	6.4 & 6.8	7.4 & 8.2	6.7 & 7.4	**8.1 & 9.0**	**7.4 & 8.1**	
Monolithic brick 4-in. brick on 1:1½:3 concrete base	4.5	4.0	5.0	4.5	**6.1**	**5.5**	4.0
2-in. to 3-in. *Asphaltic concrete on concrete base:* (1:3:6 mix)	6.5	6.0	7.0	6.3	**7.5**	**6.8**	5 to 8
(1:2½:5 mix)	6.0	6.0	6.5	6.0	**7.0**	**6.3**	
2-in. *Asphalt block on cement concrete base:* (1:2½:5 mix)	6.5	6.0	7.0	6.3	**7.5**	**6.8**	5 to 8
4-in. *Brick* (mastic joint filler) *on cement concrete base:* (1:3:6 mix)	6.8	6.2	7.6	6.9	**8.3**	**7.5**	
(1:2½:5 mix)	6.5	6.0	7.0	6.3	**7.8**	**7.1**	6 to 8
4-in. *Brick* (*cement grout filler*): (1:3:6) concrete base	5.5	5.0	6.1	5.5	**6.7**	**6.2**	5 to 8
(1:2½:5) concrete base	5.2	5.0	5.7	5.2	**6.3**	**5.7**	
5-in. *Stone block: Cement grout filler* (1:2½:5) concrete base	5.2	5.0	5.7	5.2	**6.3**	**5.7**	5 to 7

NOTE: Where two depths are given the smaller is for interior areas and the larger for exterior edge depths. Where one is given it applies to interior areas.

Typical recommended Pavement Sections showing details are given in Chap. III under the discussion of each type of pavement. The object of this table is to give a tentative basis of estimating the amount of materials and the cost per square yard for the different types suitable for different maximum load conditions.

Table 23 in conjunction with Table 17, page 100, provides a means of computing reliable comparative cost estimates for all ordinary standard types based on equal strength.

suitable when bound with bitumen and would not act well if waterbound with its own screenings, etc.

Any preliminary report should cover the sources of supply and approximate cost at pit or switch of the following materials:

Gravels suitable for	Bottom courses. Top courses. Structural concrete. First-class concrete pavement. Concrete paving base. Subbase filler.
Stone, slag, etc., suitable for	Subbase. Bottom course. Waterbound macadam top. Bituminous macadam pavement. First-class concrete pavement. Concrete paving base. Structural concrete.
Sand, suitable for	Bottom course filler. Cushion sand. Structural concrete sand. First-class concrete paving sand. Fine and coarse sand for sheet asphalt.
Miscellaneous	Bitumens. Tars. Paving brick. Stone block. Asphalt block. Stone or brick cubes.

The necessary properties of stones, gravels, sands, etc., are given in Appendix A, and in Chap. III under each type of pavement.

A convenient method of recording the location of materials is shown in Fig 52.

Unloading Points for Freight.—Provided U. S. Geological maps are obtainable, the position of sidings may be marked on the sheets. The notes for each siding show its car capacity; whether or not an elevator plant can be erected, and if hand unloading is necessary whether teams can approach from one side or two. They should also show any coal trestle that can be utilized in unloading and the location and probable cost of any new sidings that will materially reduce the length of the haul. Canal or river unloading points are shown in the same manner.

Sand, Gravel and Filler Material.—The position of sand and gravel pits and filler material are noted with their cost at the pit; if no local material is available the cost, f.o.b. at the nearest siding is given. Samples are taken and tests made.

Stone Supply.—Provided imported stone is to be used the work is simplified to determining the rate, f.o.b., to the various sidings for the product of the nearest commercial stone-crushing plant that supplies a proper grade of stone.

In case local stone is available the location of the quarries or outcrops are shown; the amount of stripping, if any, and the cost of quarry rights. If the estimate will depend upon rock owned by a single person an option is obtained to prevent an exorbitant raise in price.

In case of field or fence stone a careful estimate is made of the number of yards or boulder stone available, the owners' names, what they will charge for it, the position of the fences or piles relative to the road, or side

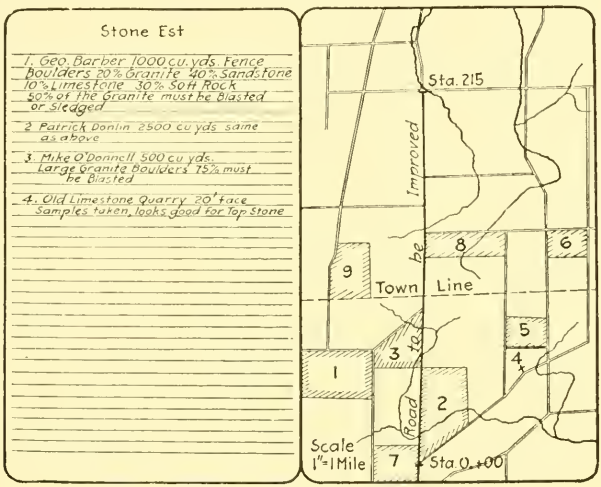

Stone Est
1. Geo. Barber 1000 cu. yds. Fence Boulders 20% Granite 40% Sandstone 10% Limestone 30% Soft Rock 50% of the Granite must be Blasted or Sledged
2 Patrick Donlin 2500 cu yds same as above
3. Mike O'Donnell 500 cu yds. Large Granite Boulders 75% must be Blasted
4. Old Limestone Quarry 20' face Samples taken, looks good for Top Stone
Sta. 215
Improved
to be
Town Line
Road
Scale 1"=1 Mile
Sta 0+00
1
2
3
4
5
6
7
8
9

FIG. 52.—Field notes stone supply survey.

roads, and if the fences are not abutting on a road or lane the length of haul through fields to the nearest road or lane. As fences are usually a mixture of different kinds of rock, the engineer estimates the percentage of granite, limestone, sandstone, etc., and the percentage that will have to be blasted or sledged in order to be crushed by an ordinary portable crusher. If there is a large excess of stone a careful estimate need not be made, only enough data being collected to determine the probable position of the crusher set-ups and the average haul to each set-up. If a sufficient supply is doubtful a close estimate is made as outlined above, and options obtained from the various owners.

Samples of the different rocks are tested (see Appendix A).

Simple field tests can be made but if the department has a testing laboratory it is better to take samples and have a careful test made and recorded. As these tests are made the location of the sample and result of the tests are recorded on a large map of the district which in the course of a few years shows at a glance the different sources of supply of accept-

able materials for the entire county or State and saves future duplication of work for reconstruction, maintenance and adjacent improvements.

The method of sampling and the amounts of material required for a good test are given in Appendix A.

Tests of road materials are an excellent guide in arriving at the final decision but judgment is essential in interpreting tests and the final decision as to use should not be vested in the Testing Department. This is not a needless caution as the author knows from experience that the arbitrary rejection of fairly suitable materials regardless of the relative importance of the road has resulted in the needless expenditure of tremendous sums of money on unimportant highways. The discussion of the use of a sliding scale of excellence is taken up in more detail in Chap. III for each type of pavement.

Cost Estimates.—Comparative construction cost estimates based on equal strength designs and the use of local materials complete the first and most important part of the decision as to the selection of type.

Maintenance and Renewal Cost.—Estimates of maintenance and renewal in conjunction with first cost of pavements and motor operation costs on different pavements complete the portion of the problem dealing with cost. The final costs are then balanced against the peculiar suitability of the different types for the road in question. This last item sometimes overbalances the economic argument although for rural highways final cost is the most important consideration (see official reports, pages 153 to 164).

Maintenance and renewal costs are open to considerable uncertainty as it is impossible to forecast future labor and material costs and also on account of inadequate and spasmodic legislative programs for maintenance and renewal. We have, however, enough data to make a rough approximation based on usual legislative and administrative conditions prevailing from 1910 to 1921. Table 24 is based on New York State figures as the author is familiar with that territory and can make necessary modifications in the available figures. By this, is meant that any published figures of State Highway Maintenance are liable to be misleading unless allowance is made for the average age of the various roads; the relative strength of the pavements and the general excellence of construction and maximum allowed roughness before reconstruction is accomplished.

Table 24 is based on pavement thicknesses recommended in this chapter and moderately effective construction and maintenance with a maximum allowable Vialog coefficient of roughness of 250 in. per mile. The costs given are for 1920 labor and material costs which are about 180 per cent pre-war rates. Similar tables can be easily compiled for any locality based on the local conditions and experience. This table is to illustrate method rather than definitely to state costs although it can

TABLE 24.—PROBABLE AVERAGE MAINTENANCE AND RENEWAL COSTS FOR DISTRICTS SIMILAR TO WESTERN NEW YORK (1922)

Computed for normal conditions. Exceptionally favorable conditions in regard to excellence of original construction and to maintenance appropriations and personnel might easily reduce maintenance and renewal costs 20 to 30 per cent (see Table 37, Chap. IV).

Type of pavement	Width, feet	Average depth, inches	Construction costs		Yearly maintenance		Renewal[3]		Total maintenance and renewal		Total interest on construction, maintenance and renewal	
			Contract cost per square yard pavement only	5 Per cent interest on cost	Pavement only per square yard	Shoulders, pitches, guard rail, etc.	Assumed normal life	Yearly cost for renewal	Per square yard	Per mile	Per square yard	Per mile
Column No. 1	2	3	4	5	6	7	8	9	10	11	12	13
Class 1 Traffic (2,000 or more Vehicles Daily 10-hour Count in Summer)												
Stone block on concrete base	18–20	12	$5.50	$0.275	$0.005	$0.020	30–35	$0.100	$0.125	$1,400	$0.400	$4,400
Brick on concrete base	18–20	11	4.20	0.210	0.015	0.020	15–20	0.160	0.195	2,150	0.405	4,450
Asphaltic concrete on cement base	18–20	10	3.50	0.175	0.020	0.020	10–15	0.170	0.210	2,300	0.390	4,300
Reinforced cement concrete	18–20	8	3.20	0.160	0.015	0.020	10–15	0.160	0.195	2,150	0.360	4,000
Penetration bituminous macadam[1]	18–20	13	2.50	0.125	0.070	0.020	5– 9	0.200	0.290	3,200	0.420	4,600
Class 2 Traffic (800–2,000 Vehicles Daily 10-hour Count in Summer)												
Reinforced cement concrete[1]	16–18	8	$3.20	$0.160	$0.010	$0.015	15	$0.145	$0.170	$1,700	$0.330	$3,300
Asphaltic concrete on macadam base	16–18	12	3.00	0.150	0.020	0.015	12	0.150	0.185	1,850	0.335	3,350
Brick cubes on macadam base	16–18	12	3.00	0.150	0.020	0.015	12	0.160	0.195	1,950	0.345	3,450
Penetration bituminous macadam	16–18	12	2.20	0.110	0.040	0.015	10	0.120	0.175	1,750	0.285	2,850
Waterbound macadam (oiled)	16–18	12	1.90	0.095	0.080	0.015	8	0.110	0.205	2,050	0.300	3,000
Class 3 Traffic (300 to 800 Vehicles Daily 10-hour Count in Summer)												
Penetration bituminous macadam	12–16	10	$1.90	$0.095	$0.030	$0.012	12	$0.100	$0.140	$1,100	$0.240	$1,900
Waterbound macadam	12–16	10	1.60	0.080	0.060	0.012	10	0.070	0.140	1,100	0.220	1,800
Class 4 Traffic (Less than 300 Vehicles Daily)												
Waterbound macadam	8–12	9	$1.50	$0.075	$0.040	$0.012	12	$0.060	$0.110	$ 650	$0.180	$1,100
Gravel[2]	8–12	10	1.00	0.050	0.040	0.012	8	0.030	0.080	500	0.130	800

[1] These types eventually resurfaced with asphaltic concrete or some form of standard block or cube surface.

[2] This type can be temporarily used under heavy traffic but for a volume of over 400 to 500 daily it generally develops disagreeable waves known as rythmic corrugations.

[3] Based on maximum vialog coefficient of 250 in. per mile without excessive maintenance charge.

be used with assurance of fair accuracy in case more detailed local figures are not available.

When all classes of road material are locally available, it can be seen that the selection of type does not have much effect on final cost but for special conditions of material supply, there is a well defined difference in final cost.

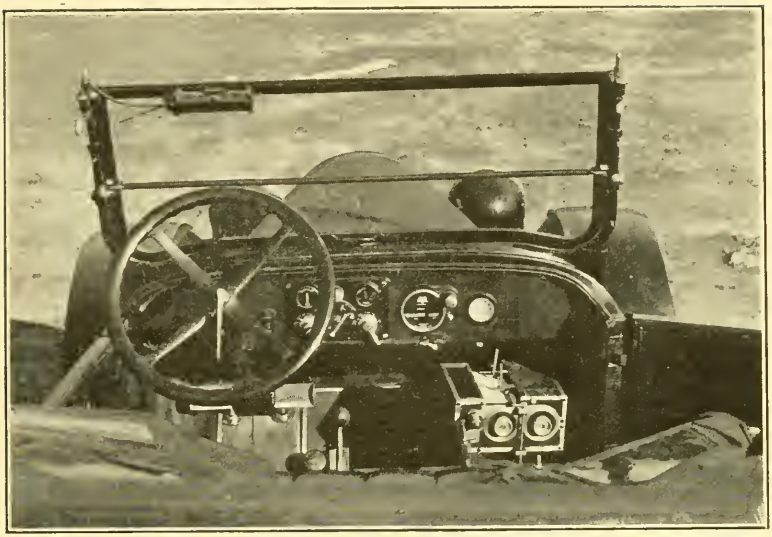
To illustrate this point, two design reports are given pages 153 to 164 showing the analysis and conclusions for two highways recently put under contract. In one case, macadam had the advantage. In the other case, a rigid pavement seemed the proper solution.

VALUE OF SMOOTH RIDING QUALITY OF PAVEMENTS

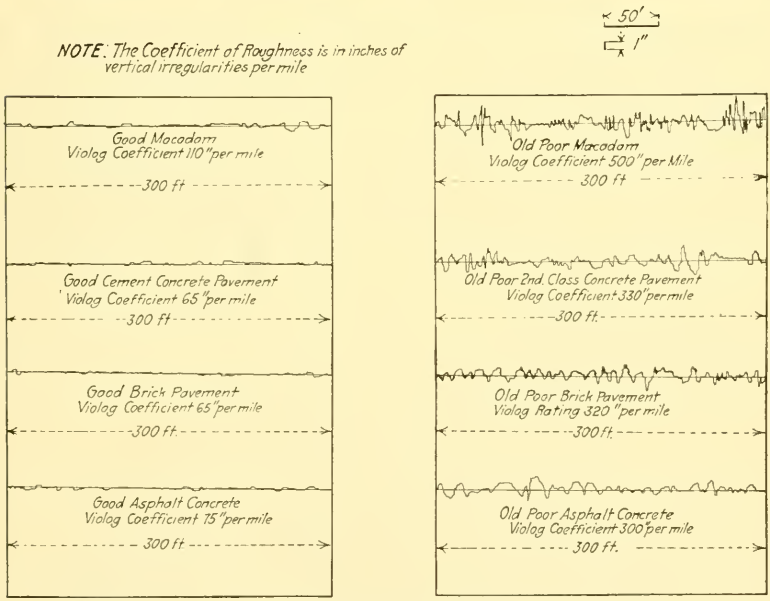
A smooth easy riding pavement is desirable on the score of personal riding comfort, reduced cost of motor operation (gasoline, tires and jar damage) and reduced stress on the pavement due to impact of heavy trucks. Surface irregularities will vary with the type of pavement, care of construction, age of pavement and perfection of maintenance and they gradually increase as the pavements age until reconstruction becomes necessary.

Probably the most satisfactory method of measuring such irregularities at present (1923) is by means of the Vialog invented by Harley Dunbar of the New York State Dept. of Highways and manufactured by the Good Roads Machinery Co. of Kingston. This machine can be attached to an automobile. It records automatically in graphic form as shown in the chart on page 143 the surface irregularities of the road. The machine is calibrated for the auto being used and the speed at which it is driven by means of careful test runs over a pavement of known irregularity. A duplicate record is made and the results agree remarkably well. The results can be examined for individual bumps or hollows or the average condition of the surface expressed as inches of irregularity per mile of road. This coefficient is reliable as a measure of relative roughness and of some value as a measure of absolute roughness. By means of records of this kind it is possible to set a reasonable limit of irregularity for acceptance of pavements of different types. It is also useful in keeping yearly records of the general condition of a state system and check up the effectiveness of the maintenance and renewal programs. Being a mechanical device it eliminates personal opinion and is a very useful instrument in highway work. The results of investigations of 2,000 miles of New York State Highways in 1923 can be summed up roughly as follows:

From the standpoint of riding comfort a pavement does not become disagreeably rough until the coefficient of roughness exceeds about 250 in. per mile. The report on the 2,000 miles investigated covers pave-

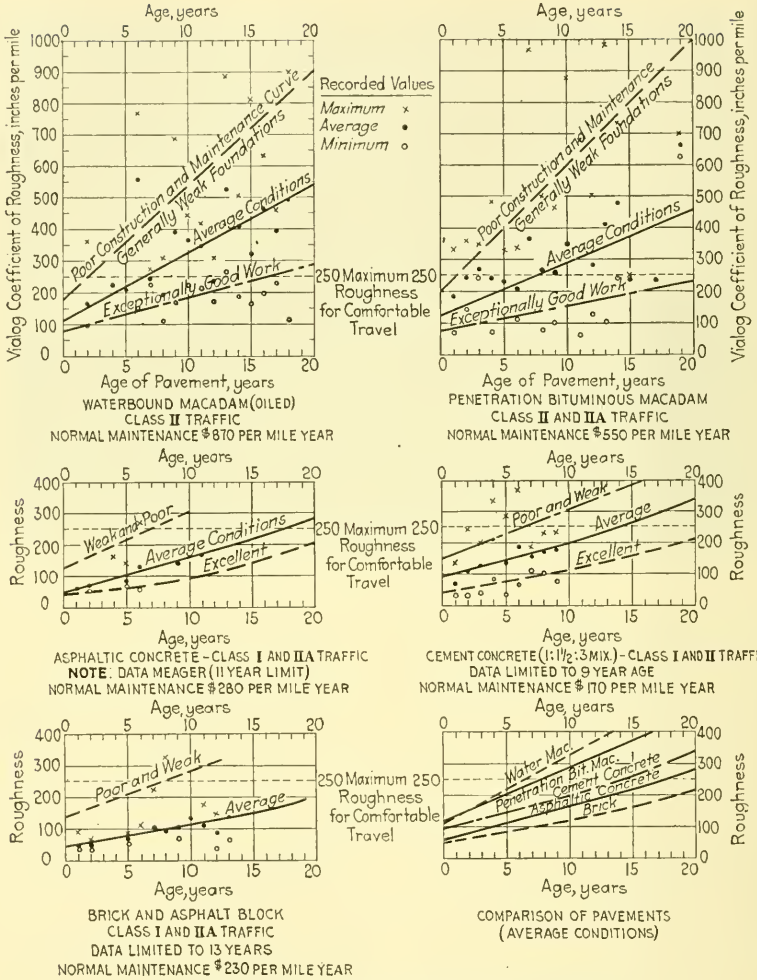


Vialog on car.



NOTE: This Chart illustrates graphically the wide range in surface roughness with attendant resistance to traction on all Standard Pavements due to age and lack of effective Maintenance. The practical use of the Vialog in connection with Highway Programs is discussed in Chap 2 A reasonable allowance for increase in business motor operation cost due to roughness is approx. $80 per mile per year per 100 vehicles average mixed traffic daily (36,500 yearly) for each 100" increase in Vialog Coefficient.

CHART A.—Vialog records of sur face roughness (showing effect of age).



GRAPHS SHOWING WIDE RANGE AND AVERAGE VALUE OF VIALOG CO-EFFICIENT OF ROUGHNESS FOR DIFFERENT PAVEMENTS AT DIFFERENT AGES. (NEW YORK STATE 1923)

Based on average maintenance, that is, no specially high maintenance has been used to hold the roughness to a specified maximum. Reconstruction is resorted to when normal maintenance becomes ineffective.

***NOTE**: These graphs show the wide range in results obtained under Public Works Programs and show conclusively the distinct advantage of good Engineering Control. Any type of pavement well designed, constructed and maintained will give satisfactory results as far as traffic operation cost is concerned*

To anyone personally familiar with this district these records have a human as well as a scientific interest. It is possible to trace the gradual loss or gain in interest in the success of the various types depending on the sympathies of the different administrations and they also show the effect of knowledge and experience of the inspectors with different types.

CHART B.

ments of brick, asphaltic concretes, cement concrete, penetration bituminous macadam and waterbound macadam oiled. There is a wide range in roughness for each type depending on age, maintenance, etc. All these types can be constructed originally and maintained for a considerable time in a comfortable condition for traffic. They all, in time, become rough and require resurfacing on the score of comfort and motor operating costs. The vialog records verify the fact which we all know from common experience that the higher priced pavements such as asphaltic concretes, cement concrete and brick have a lower average roughness than the macadam type for the first few years after which it becomes a matter of maintenance or reconstruction as to which has the advantage. (See also page 144.)

Mr. Dunbar gives some tentative values subject to future change as follows. He recommends a maximum value of 50 in. for acceptance of

Type of pavement	New pavements, good condition		Old pavements, poor condition
	Range, inches per mile	Average, inches per mile	Range, inches per mile
Cement concrete	25 to 80	65	250 to 600[1]
Brick	20 to 80	65	250 to 300
Asphaltic concrete	35 to 90	75	250 to 300
Penetration bituminous macadam	80 to 150	100	250 to 800
Waterbound macadam (oiled)	90 to 170	110	250 to 1,000

[1] Low-grade 1:2½:5 concrete.

newly constructed concrete, brick or asphaltic concretes and a maximum value of 100 in. for new bituminous macadam. The average roughness of roads at present under reconstruction runs from 500 to 700 in. per mile.

EFFECT OF ROUGHNESS ON MOTOR OPERATION COSTS

Roughness increases the gasoline consumption of motors and the tire and engine wear. Any attempt to figure this closely is a useless proceeding but the general fact must be borne in mind in arriving at any reasonable conclusion as to the economic value of pavements and the necessity for effective maintenance. In time vialog records will be coordinated with gasoline consumption. No experiments along this line have yet been made. The following figures based on what meager vialog records we have must be considered as speculative as far as actual cost of operation is concerned. However they check the gasoline con-

sumption tests shown in Table 2A, page 19, and serve to illustrate the value of smoothness and to reinforce the general arguments given in Chap. I, page 20.

Mr. Dunbar states that on a road having a coefficient of about 50 in. his chart distance measured by wheel revolutions was exactly equal to the actual lengths of the roads. Where the coefficient reached 500 to 700 in. the chart distance by wheel revolutions exceeded the actual survey measured length of the road by from 100 to 200 ft. per mile. That is roughness actually increases wheel revolution due to jump, free spin and extra length, exactly how much we do not know. A conservative assumption is 0.5 per cent per 100 in. increase in vialog coefficient.

Roughness virtually increases the rate of grade of the road. A conservative figure is 0.2 per cent per 100 in. increase in vialog coefficient.

Considering gasoline consumption alone and using the values given on page 98 of the first book of this series ("Highway Location") for distance and grade we can derive an increase in cost of motor operation of about 8 per cent.[1] This amounts to about $100 per mile per year for 100 average vehicles daily (36,500 yearly) for each 100 in. increase in vialog coefficient. Making the same assumptions discussed in book one in regard to the actual value of gasoline saving considering pleasure traffic and snow and ice during a portion of the year this is reduced to $50 per mile per year per 100 vehicles daily. For different volumes of traffic this is expressed in tabular form page 147, assuming a vialog coefficient of 50 in. per mile as perfection.

In a similar way an approximation can be derived for tire wear. Any actual cost value for tire wear due to minor differences of roughness is a very illusive quantity. Recent investigations have established that the difference in tire wear over gravel roads with loose small pebble surface as compared with a smooth new rigid pavement may amount to as much as $0.01 per vehicle mile. The actual difference in tire wear for ordinary road conditions considering ice and snow in winter for any well maintained gravel or macadam road with a bituminous surface carpet as compared with well maintained rigid base pavements cannot amount to much. We will assume some speculative figures merely to bring out the fact that there is some difference in cost of this phase of road travel over different types.

Ordinary tire wear on improved roads is assumed at $0.015 per average vehicle mile for roughness of say 200 in. vialog rating. A well maintained and renewed road system should not range more than 50 to

[1] Allowing for an average difference in vialog coefficient of roughness of 50 in. per mile between average macadam and average Class A surfaces the difference in gas consumption is 4 per cent. According to Table 2A, page 19, actual experiment gives a value of 5 per cent.

Volume of total traffic, vehicles per day	Vialog coefficient, inches per mile.					
	50	100	200	300	400	500
	Values below are estimated yearly saving in business consumption of gasoline					
100	$0	$ 25	$ 75	$ 125	$ 175	$ 225
200	0	50	150	250	350	450
300	0	75	225	375	525	675
400	0	100	300	500	700	900
500	0	125	375	625	875	1,125
1,000	0	250	750	1,250	1,750	2,250
1,500	0	375	1,125	1,875	2,625	3,375
2,000	0	500	1,500	2,500	3,500	4,500
3,000	0	750	2,250	3,750	5,250	6,750
4,000	0	1,000	3,000	5,000	7,000	9,000
5,000	0	1,250	3,750	6,250	8,750	11,250
10,000	0	2,500	7,500	12,500	17,500	22,500

300 in. per mile. The increase in wheel travel distance as between 50 to 500 in. rating amounts to about 2 per cent. The added jar damage above 250 in. rating probably does considerable more damage. We will assume the same rate of tire cost as for gasoline previously derived 8 per cent per 100 in. vialog increase. This amounts to approximately $50 per mile per year for 100 average vehicles daily. Combining this value with the gasoline saving the table on page 148 is derived.

This table indicates in a general way the importance of keeping a system in fairly smooth riding condition. To illustrate with the New York System Division 7. The coefficient of roughness of most roads when actually reconstructed is about 500 to 700. This gives an average coefficient for the life of the pavement of about 300 to 400. The average volume of traffic for this territory is about 800 to 1,000 vehicles per day (Class 2 traffic). That is the cost of motor operation due to the degree of perfection actually attained probably is increased about $2,000 per mile per year over a system in perfect condition. As later discussed it is probably impracticable to attempt to maintain and renew a system with a maximum allowable roughness before renewal of under 250 in. vialog rating. If our system were maintained on this basis the average coefficient would be about 150 to 200 which might result in a yearly saving in motor operation of about $800 per mile ($2,000–$1,200).

TABLE OF POSSIBLE DIFFERENCE IN MOTOR OPERATION COST PER MILE YEAR FOR DIFFERENT VOLUMES OF TRAFFIC AND DIFFERENT DEGREES OF SURFACE ROUGHNESS (1923 COST CONDITIONS)
(Based on Gas Consumption and Tire Wear)

Volume of traffic, vehicles per day	Vialog coefficient, inches per mile					
	50[1]	100	200	300	400	500
100	$0	$ 40	$ 120	$ 200	$ 280	$ 360
500	0	200	600	1,000	1,400	1,800
1,000	0	400	1,200	2,000	2,800	3,600
1,500	0	600	1,800	3,000	4,200	5,400
2,000	0	800	2,400	4,000	5,600	7,200
3,000	0	1,200	3,600	6,000	8,400	10,800
4,000	0	1,600	4,800	8,000	11,200	14,400
5,000	0	2,000	6,000	10,000	14,000	18,000
10,000	0	4,000	12,000	20,000	28,000	36,000

[1] Vialog rating of 50 in. considered as practical perfection.

It is a well recognized fact that we have been short of funds and that our roads are too rough in their last stages before reconstruction. The average actual expenditure for maintenance and renewal has been about $1,100 per mile for the last few years. The discussion of maintenance cost in Chap. IV indicates that approximately $1,500 to $2,000 per mile per year is necessary for this territory; the above data indicates that this increase is probably justified from the standpoint of economic motor operation as well as for the more obvious reason of comfort in riding.

DIFFERENCE IN OPERATION COST ON DIFFERENT SURFACES

A rough approximation can now be derived on the assumption that roads will be maintained and renewed on the basis of a maximum coefficient of roughness of 250 in. vialog rating.

Class B.—The macadam type of surface has an initial rating of 100 in. and a final rating of 250 in. or an average of 175 in.

Class A.—The asphaltic concretes, cement concrete and brick range from 50 to 250 in. average 150 in. giving an average difference between class *A* and *B* for total life of pavement of about 25 to 50 in. vialog rating. Expressed in money value as yearly cost and capitalized cost for different volumes of traffic the following table is constructed.

TABLE OF INCREASED COST OF OPERATION ON MACADAM TYPE OF SURFACE (CLASS B) COMPARED WITH CLASS A SURFACES (1923 COST CONDITIONS)

Volume of daily traffic	Increased yearly cost of operation		Capitalized value of increased cost at 5 per cent	
	per mile	per sq. yd. 18-ft. road	per mile	per sq. yd. 18-ft. road
100	$ 20	....	$ 400	$
500	100	0.01	2,000	0.20
1,000	200	0.02	4,000	0.40
2,000	400	0.04	8,000	0.80
3,000	600	0.06	12,000	1.20
4,000	800	0.08	16,000	1.60
5,000	1,000	0.10	20,000	2.00

In computing the total yearly cost of a pavement to the community it is just as well to give some weight to this item. (See Official reports, pages 158 and 161.)

For average conditions in Division 7, Western New York, considering construction, maintenance, renewal, interest on construction and difference in motor operation cost, the general conclusion to be drawn is that the macadam type of surface usually becomes uneconomical at a volume of traffic of between 1,500 to 2,000 vehicles daily. At this point an old macadam road can be resurfaced with asphaltic concrete and brought up to the operation efficiency of Class A pavements.

The student is again cautioned not to overemphasize the importance of hair splitting economic value figures. They are included to illustrate general principles and the values and conclusions given throughout this text have been adjusted to agree with actual observed road conditions.

EFFECT OF SMOOTHNESS ON IMPACT

Table No. 11, page 80, gave a rough summary of the U. S. Office of Roads investigations on impact for known surface irregularities. Impact increases rapidly with the roughness and becomes a very destructive element unless the pavements are kept moderately smooth by effective maintenance. The section on design, page 81, assumed impact allowances based on $\frac{1}{4}$ to $\frac{1}{2}$ in. irregularities. An examination of the vialog records show that such irregularities are quite common and continuous on the macadam type for an average coefficient of 120 to 200 per mile and occur at joints and cracks quite frequently on the rigid type of pavement with coefficients as low as 65 to 100 per mile. Where the coefficient rises to 300 to 500 per mile surface irregularities of 1 to 2 in. are quite common and the pavement becomes not only uncomfortable and expensive to operate over but also is stressed beyond the design loading.

TENTATIVE MAXIMUM ALLOWABLE VIALOG RATING

From the standpoint of comfort, cheapness of operation and cost of construction due to impact stresses it seems desirable to place a maximum limit of roughness at about 200–250 vialog rating. As a road ages the cost of maintenance will increase to retain this value and when the maintenance cost exceeds the proper limit for each type reconstruction or resurfacing must be resorted to. It is believed that if rural pavements are designed according to the principles outlined in this chapter that the maintenance costs and average life before renewal becomes a practical necessity either on the score of economy or appearance or travel comfort will correspond closely with the figures derived in Chap. IV.

An examination of the vialog records in conjunction with ordinary New York State maintenance costs and procedure indicates that it is impracticable to attempt to reduce the maximum coefficient of allowable roughness below 200 to 250 as it would increase maintenance and renewal costs out of all proportion to the benefits derived.

A rough approximation of the maximum economic limit of maintenance cost per year for the different types is given below. When this limit is exceeded resurfacing or reconstruction is desirable from the standpoint of paving cost.

Type of pavement	Class I traffic		Class II traffic		Class III traffic	
	per sq. yd.	per mile	per sq. yd.	per mile	per sq. yd.	per mile
Asphaltic concretes	$0.17	$1,700	$0.14	$1,200		
Brick[1]	0.17	1,700	0.14	1,200		
Cement concrete[1]	0.17	1,700	0.14	1,200		
Bituminous macadam	0.17[1]	1,700	0.15	1,300	$0.12	$1,000
Waterbound macadam (oiled)	....	.....	0.18	1,600	0.13	1,100

[1] Resurfaced with bituminous concrete.

As a matter of fact maintenance costs rarely reach these maximums before renewal is resorted to as the trouble and inconvenience to traffic from excessive maintenance work is the deciding factor rather than low total cost of maintenance and renewal. In Division 7 when we have to spend around $1,000 per mile to keep a road in fairly good shape reconstruction is resorted to on the score of practical expediency.

SPECIAL QUALIFICATIONS AND DRAWBACKS OF DIFFERENT PAVEMENTS

Limitations Imposed by Steep Grades.—The following tabulations represent current practice in regard to the steepest advisable grades on which various types are satisfactory considering safety and maintenance costs.

TABLE 25A

(Taken from Agg's "Roads and Pavements.")

SURFACE MATERIAL	PER CENT
Wood block	3
Asphalt block	6
Brick	10
Sheet asphalt	5
Asphaltic concrete	7
Bituminous macadam (seal coat)	8
Bituminous macadam (no seal coat)	10
Cement concrete[1]	8
Hillside brick	12
Stone brick	12

[1] Hard to construct on grades over 5 per cent.

TABLE 25B

SURFACE MATERIAL	PER CENT
Wooden block	2
Asphalt block	4
Brick (grout joints)	5
Brick (mastic joints)	8
Concrete[1]	5 to 7
Bituminous macadam with flush or squeegee coat	5
(In sandy country, 6 per cent when coarse sand is sprinkled on surface.)	
Bituminous macadam without squeegee	8
Waterbound macadam	8
"Hillside" brick	12
Stone block with open joints	12

[1] Hard to construct on grades over 5 per cent.

On steep grades, the author believes that stone block is the best solution, hillside brick second, penetration one coat pour bituminous macadam third, and waterbound macadam fourth. The last two become slippery if maintained by surface oiling and it has been necessary in some cases to build a specially wide shoulder treated with gravel or stone for horse traffic. It is very difficult to get a satisfactory surface on concrete on grades over 5 per cent.

CLASSIFICATION FOR SAFETY OF TRAFFIC

The sheet asphalts, and similar constructions are dangerous for high speed traffic even on fairly level grades during sleet storms or light rains and are not recommended for roads outside of villages except for reconstruction where the large economic saving due to the use of this type overcomes the factor of reduced safety. Slipperyness can be partially overcome by the use of a larger percentage of small stone in the mix, such as Topeka, Amiesite, Warrenite, etc.

Bituminous macadams, concrete, brick, stone block, waterbound macadams and small stone or brick, cubes can be ranked as safe surfaces for high-speed traffic.

Recommended Types.—Bituminous macadams are recommended for Class II traffic and resident village streets.

Waterbound macadam for Class III traffic.

Concrete for Class I outside of villages.

Brick for village business streets.

Stone block for hills on Class I traffic.

Asphalt block for extremely heavy Class I traffic.

Sheet Asphalt, Topeka, etc., are to be avoided for original construction where traffic travels at high speed but its use for reconstruction has decided advantages from an economic standpoint. Its most suitable location is a resident village or city street or for heavy slow traffic.

FAILURES

The common causes of failure of different pavements due to structural defects are as follows. The details of inspection are taken up in the fourth book of this series but are briefly outlined in Chap. III of this volume for the benefit of the student.

Stone Block.—Failures rare; will stand lots of abuse in construction.

Asphalt Block.—Failures rare. When they occur due to poor block.

Waterbound Macadam.—Failures rare. When they occur are generally due to poor rock, small-sized stone in top courses, and insufficient rolling or puddling.

Penetration Bituminous Macadam.—Failures not uncommon due to the use of too much soft binder; unequal application and overheating of binder. The asphalt companies advocate the use of too much bitumen.

Concrete.—Failures not uncommon due to inferior materials particularly dirty sand and to poor manipulation, weak mix, and too much water content.

Brick.—Failures not uncommon due to poor brick and careless grouting.

Sheet Asphalt and Topeka Mix.—Failures not uncommon due to overheating and poor mix.

Example of Design Reports.—The following reports illustrate the practical application of the data included in Chaps. I and II. These reports refer to recently designed roads in Division 7, N. Y. State Department of Highways. They illustrate conditions resulting in the recommendation of macadam for one case and a rigid pavement for the other case. The notes in brackets show the location of data in this book which were used in connection with the official reports.

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SAMPLE DESIGN REPORT

Rush-Mendon Pt. I. Road No. 1392.
Monroe County, New York.
Division Engineer,
Rochester, N. Y.
Dear Sir:

Find attached design report, Road No. 1392.

Considering traffic, soil and local material conditions, we recommend a 16-ft. Penetration Bituminous Macadam Pavement varying in depth from 10 to 20 in. and averaging 11 in. for the entire road with gravel shoulders, 6 per cent maximum grade, 301-ft. minimum radius of curvature, 350-ft. minimum sight distance, 24-ft. to 32-ft. width of grading section, 1½ to 1 slopes and cut to fill ratios of 1.10 to 1.30. A satisfactory pavement of this character is estimated to cost approximately $1.60 per square yard for construction, $0.035 per square yard per year for ordinary maintenance and $0.11 per square yard per year for renewals over a long term of years. The total estimated construction cost is $100,000. The detail report follows:

DETAIL REPORT

1. Location and Length.—Proposed Road No. 1392 extends from Road 1393 to Road 1187 a distance of 3.69 miles. It completes the east and west state system in this locality and gives a continuous road from Caledonia to Canan-

daigua via Scottsville. It is not likely that this route will change the volume of traffic on Route 6 (Canandaigua to Caledonia via Avon) as Route 6 is shorter but it will serve as a convenient by pass during times of reconstruction on Route 6.

2. Traffic Classification.—Road 1392 is on the verge between Class II and Class III Traffic according to Classification Map (Frontispiece). It will probably carry about 400 to 1,000 vehicles daily which is lower limit Class II or upper limit Class III.

3. Grades and Alignment.—The existing alignment is quite good and only requires minor improvements. The existing grades are in the main easy with a few short steep grades of 8 to 9 per cent. The new profile as a rule follows the existing road closely with short grade reductions. The total rise and fall for the old and new road is about the same. The proposed grading will have some effect on motor operation cost but is largely useful in providing a convenient width for traffic and a smooth bed for the pavement. In figuring the economic value of the improvement grade reductions can be given some weight for this road. (See accompanying tabulation based on Curve 1, Fig. 5, page 16.) Total grading cost estimated at $32,000. Maximum economic benefit of grading estimated at $18,000.

4. Suitable Types of Pavement (Based on Traffic Classification).—For lower limit Class II Traffic, either Penetration Bituminous Macadam or Waterbound Macadam Oiled is suitable (see Table 9, page 68). Reinforced cement concrete might be considered under specially favorable conditions of Material Supply but for the volume of traffic expected there would probably have to be unusually strong reasons of expediency to warrant consideration of this type. For comparative estimate purposes, the cheapest possible type of this pavement will be used (see Fig. 110, page 255) 7 in. uniform depth 1:2:4 mix 1.7 cement content 50-lb. reinforcement per 100 sq. ft. of pavement.

5. Soils.—The subgrade soils are as follows:

Soil on Road 1392

Station	Soils	Station	Soils
0 to 2	Muck	142 to 154	Loam clay
2 to 72	Loam gravel sand	154 to 157	Loam sand
72 to 106	Loam gravel	157 to 160	Loam muck
106 to 110	Sand loam	160 to 165	Loam clay
110 to 126	Loam clay	165 to 172	Loam sand
126 to 130	Loam muck	172 to 181	Clay loam
130 to 142	Loam gravel	181 to 194	Loam clay

Named in order of greatest amount of each first.

COMPARISON CAPITALIZED MOTOR OPERATION COST, OLD AND NEW PROFILE
(Based on Curve 1, Fig. 5, Page 16)

Rate of grade, per cent	Estimated capitalized cost per 100 vehicles daily per foot of distance	Old profile		New profile	
		Length, feet	Amount 100 vehicles daily	Length, feet	Amount 100 vehicles daily
1.0 or less	$ 9.10	8,300	$ 75,530	7,900	$71,890
1.5	9.12	800	7,296	400	3,648
2.0	9.15	1,200	10,980	1,700	15,555
2.2	9.17	200	1,834	800	7,336
2.4	9.19	500	4,595	700	6,433
2.6	9.21	600	5,526	300	2,763
2.8	9.23	1,000	9,230	800	7,384
3.0	9.25	800	7,400	1,600	14,800
3.2	9.28	800	7,424	500	4,640
3.4	9.31	500	4,655	500	4,655
3.6	9.34	400	3,736	1,000	9,340
3.8	9.37	100	937	.....	.....
4.0	9.40	400	3,760	700	6,580
4.2	9.45	300	2,835	200	1,890
4.4	9.50	400	3,800	400	3,800
4.6	9.56	500	4,780	100	956
4.8	9.63	200	1,926	200	1,926
5.0	9.70	300	2,910	100	970
5.2	9.80	100	980	100	980
5.4	9.90	100	990	.....	.....
5.6	10.00	400	4,000	300	3,000
5.8	10.10	400	4,040	400	4,040
6.0	10.20	.....	.....	800	8,160
6.5	10.70	.....	.....		
7.0	11.20	100	1,120		
7.5	11.85	500	5,925		
8.0	12.50	200	2,500		
8.5	13.25	100	1,325		
9.0	14.00	100	1,400		
9.5	14.75	.....	.....		
10.0	15.50	200	3,100		
100 vehicles daily total			$184,534	.....	$180,746
500 vehicles daily total			$922,000	.....	$904,000

Maximum economic value of grading $18,000. ($922,000—$904,000)

6. Uniform Strength Design. (Alternate Pavement Estimates).

NOTE.—Macadam depths based on Table 17, page 100. Concrete pavement based on Fig. 110, page 255.

Sta. to sta.	Soil	Grading conditions	Total pavement depths	
			Macadam, inches	Concrete 1:2:4 mix, 0.5-lb. reinforcement per square foot, inches
0– 2	Muck	Gravel fill 4 ft.	8	7
2– 49	Loam gravel	Light cuts and fills	10	7
49– 51	Loam gravel	Fill 2 to 4 ft.	9	7
51– 72	Loam gravel	Light cuts and fills	10	7
72– 89	Loam gravel	Light cuts and fills	10	7
89– 91	Loam gravel	Fill 2 to 5 ft.	9	7
91–106	Loam gravel	Light cuts and fills	10	7
106–110	Sand loam	Light cuts and fills	9	7
110–112	Loam clay	Fill 2 to 4 ft.	10	7
112–123	Loam clay	Light cuts and fills	12	7
123–126	Loam clay	Fill 2 ft. deep	11	7
126–130	Loam muck	Light cuts and fills	20	8[1]
130–142	Loam gravel	Light cuts and fills	10	7
142–149	Loam clay	Light cuts and fills	12	7
149–153	Loam clay	Fill 1.5 deep	11	7
153–157	Loam sand	Light cuts and fills	10	7
157–160	Loam muck	Light cuts and fills	20	8[1]
160–165	Loam clay	Light cuts and fills	12	7
165–172	Loam sand	Light cuts and fills	10	7
172–181	Clay loam	Light cuts and fills	13	7
181–194	Loam clay	Light cuts and fills	12	7

Average depth macadam 11 in.
Use normal 10 in. with extra subbase allowance.

[1]12-in. gravel subbase under concrete.

NOTE.—The average of 11 in. is liberal as Road 502 at east end of this road has served same class of traffic with same general soil conditions with a depth of 9 in. for the last 10 years with only minor area weakness.

Road 502 has a 6-in. boulder base and a 3-in. penetration bituminous macadam top.

We recommend for this road a boulder base 6½ to 16½ in. deep laid in layers not exceeding 8-in. depth filled with coarse gravel or crushed stone and capped with a 3½-in. penetration bituminous macadam top.

7. Amounts of Material Required.—There are 37,000 sq. yd. of pavement on this road.

Macadam type of pavement will require approximately
7,800 cu. yd. gravel or boulder foundation
3,700 cu. yd. 3½-in. top course
75,000 gal. bitumen (binder) or
12,000 gal. surface oil.

Concrete Pavement will require approximately
7,250 cu. yd. 1:2:4 concrete
12,300 bbl. cement
166,000 lb. steel
10,000 lin. ft. expansion joints.
400 cu. yd. gravel foundation

8. Materials Available.—For details, see Survey field book 1392. A limited supply of local boulder fence stone fit for subbase or crushed bituminous macadam top is available. Unlimited supplies of coarse hard gravel fit for subbase, subbase filler or concrete is available. Imported materials can be unloaded at Rochester Junction or Rush and delivered with short hauls. Water supply abundant year round from Honeoye Creek.

For purposes of estimating concrete pavement, use Mead's gravel pit Sta. 50.

For purposes of estimating macadam, use local boulder subbase bottom entire length filled with gravel or local crushed stone and capped with 3½-in. consolidated depth of local granite top Sta. 0–100 and imported limestone top Sta. 100–195. There are 10,000 to 12,000 cu. yd. of boulder available but in order to get this amount, the farmers will insist on bottoms being cleaned up which will necessitate blasting large granite boulders which can be used to best advantage for local stone top Bituminous Macadam Type. For Waterbound Macadam, imported limestone will have to be used.

On this basis, fair comparative preliminary estimates of cost are given in Article 9. Detail cost figures are on file in estimate book under Road 1392.

9. Comparative Cost Estimates.

Type	Average thickness, inches	Costs per square yard of pavement				
		Estimated construction cost	Yearly interest, 5 per cent	Yearly maintenance, Table 24, page 141	Yearly renewal, Table 24, page 141	Total yearly charge
Waterbound[1] macadam.....	11	$1.50	$0.075	$0.065	$0.10	$0.24
Bituminous[2] macadam.....	11	1.60	0.08	0.035	0.11	0.225
Cement concrete.....	7	2.30	0.115	0.010	0.12	0.245

[1] Limestone top (oiled).

[2] Part granite, part limestone top.

Grading, culverts and incidental items are estimated at $43,000 for all types of pavement.

Total estimated construction costs for different widths of different types are tabulated below:

Type of pavement	Widths of pavement					
	8 ft.	10 ft.	12 ft.	14 ft.	16 ft.	18 ft.
Water macadam	$70,000	$78,000	$85,000	$ 99,000	$ 99,000	$105,000
Bituminous macadam	73,000	80,000	88,000	94,000	102,000	109,000
Cement concrete	85,000	96,000	108,000	116,000	128,000	138,000

Effect of Motor Operation on Total Cost of Types to the Community (Based on Table, Page 149, Chap. II)

For a volume of 500 vehicles daily the comparative total yearly charge against the different types proposed is as follows:

Waterbound macadam	$0.24	+ $0.01	= $0.25
Bituminous macadam	0.225	+ 0.01	= 0.235
Cement concrete	0.245	+ 0.00	= 0.245

10. Reasonable Maximum Expenditure.—Reasonable expenditures based on reduction in traffic operation cost can be estimated approximately as follows:

Grade reduction value (Article 3 of this report) is estimated at not to exceed $18,000.

Pavement value is roughly estimated as follows: The old existing road is a narrow gravel road in fairly good condition; the new pavement will not probably reduce the cost of operation over $0.01 per vehicle mile but it will add materially to the safety and convenience of operation which are classed as intangible benefits. Actual reductions in operation cost (see Table 3, page 22) will not probably justify construction expenditures of over $16,000 per mile for 500 vehicles daily or a total of approximately $60,000. The total maximum economic value including grading and pavement does not probably exceed $75,000. Any expenditure over this amount must be charged to convenience, pleasure and other desirable intangible benefits. This indicates that caution should be exercised in running the cost up needlessly. Article 9 indicates that in order not to exceed the economic limit a 10-ft. width of Waterbound Macadam is the most feasible solution. A pavement as narrow as this is not in accord with the general highway policy which is based on a minimum width of 16 ft. on the score of intangible benefits. We therefore recommend the use of 16-ft. width of Bituminous Macadam estimated to cost $100,000. This recommendation seems to be warranted as this type will satisfy traffic demands without running the construction cost up needlessly and without increasing the total final cost of road including Maintenance, Renewal and motor operation over and above the final cost resulting from the use of a more expensive first cost pavement.

Signed W. G. Harger,
Designing Engineer.

Remarks.—For the interest of the reader, actual procedure on this road was as follows: Plans were first prepared for cement concrete pavement. Before these were let, the administration changed and the plans were revised for Bituminous Macadam 7-in. Boulder Base, 3-in. Imported Slag Middle Course and 2½-in. Imported Limestone top, Engineer's estimate of cost $123,000. The road was constructed on this basis for $102,000 actual contract cost; the pavement proper cost $65,000 or approximately $1.75 per square yard. This final solution was an improvement over the first plans. A careful engineering design could probably have decreased the cost at least $8,000 to $10,000 as shown in the body of this report by a more complete utilization of local materials and more variation in depth to meet varying soil conditions and a somewhat more economical grading design.

PRELIMINARY DESIGN REPORT

MT. MORRIS VILLAGE STATE-COUNTY HIGHWAY LIVINGSTON COUNTY, NEW YORK STATE

1. Location and Length.—The proposed improvement extends from the south corporation line at Buck Run northerly along Main St. to State St. a distance of approximately 4,800 ft., and on Chapel St. from Main St. to Clinton St. a distance of approximately 400 ft. This construction will complete the state system through Mt. Morris Village and furnish the final connecting link between the following previously improved roads Nos. 482, 855, 5,270 and 5,665.

2. Grades and Alignment.—The grades are easy and the alignment straight. No grade reductions will be required nor will any rights of way be necessary to improve the alignment.

3. Traffic Classification (Based on Traffic Classification Map, See Frontispiece).—This road is Class II from Sta. 0–26 (Buck Run to Erie St.) and on the verge between Class II and Class I from Sta. 26 to 48 (Erie St. to State St.). From Sta. 26–48 it lies in the business section of the village and takes all traffic to the Erie Ry. Station.

4. Suitable Types of Pavement (In Respect to Traffic Classification).—Between Sta. 0–26 (Class II Traffic) either Bituminous Macadam or Reinforced Cement Concrete are suitable.

Between Sta. 26–48 (Class I Traffic) either Brick or Asphaltic Concrete on Concrete Bases or Reinforced Cement Concrete are suitable.

(For suitability of pavements see Table 9, page 68.)

5. Soils.

The subgrade soils are as follows:

Sta. 0– 4	Ordinary loam
Sta. 4– 7	Quicksand
Sta. 7– 22	Ordinary loam
Sta. 22– 48	Gravelly soil
Sta. 880–884	Gravelly soil

6. Equal Strength Design (Based on Table 17, Page 100 and Table 23, Page 137).—Considering the above list of soils and that the road is entirely in cut, the following depths of pavement are recommended:

TOTAL PAVEMENT THICKNESS IN INCHES

Location	Type			
	Bituminous macadam	Reinforced concrete 0.65 lb. per sq. ft.	3-in. asphaltic concrete surface on concrete base	4-in. brick on concrete base
Sta. 0– 4	13	8	10	11
Sta. 4– 7	24	8[1]	10[2]	11[2]
Sta. 7– 22	13	8	10	11
Sta. 22– 48	10	7	9	10
Sta. 880–884	10	7	9	10

[1] Bottom and top reinforcement and subbase.
[2] Gravel subbase.

7. Materials Available.—Local sand and gravel fit for concrete paving base, culverts or subbase bottom courses are available as follows:

Gravel pit owned by Village of Mt. Morris located 2,000 ft. (down hill haul) west of Sta. 46. This gravel if screened ought to be suitable for the coarse aggregate for concrete paving base but is not probably good enough for concrete pavement. This pit has been sampled 7–914 and submitted to Albany for approval. The price of this gravel is 75c. per cubic yard at the pit. This gravel is suitable (pit run) for subbase under macadam Sta. 0–22. Seven thousand cubic yards are available.

Sand pit, owned by Jerry Donovan, located 2 miles west of Sta. 46. Unlimited quantity. Rather uniform fine grained sand. Field test showed 3 per cent loam. Probably good for any grade of concrete except concrete pavement. Sample 7–913 taken and submitted to Albany for approval. Price at pit 50c. per cubic yard.

Imported sand fit for any grade of concrete can be obtained from the Valley Sand, Penn. Ry. delivery at $1.45 per ton f.o.b. Mt. Morris. Screened gravel from the same source $1.35 per ton f.o.b. Mt. Morris.

Imported crushed limestone acceptable for all work can be obtained from Le Roy $2.05 per ton f.o.b. Mt. Morris, Erie Ry. delivery.

Crushed slag fit for macadam bottom course, $2.35 per ton Erie Ry. delivery.

Brick.—$41.50 per 1,000 f.o.b. Mt. Morris any railroad.

Cement.—$2.35 f.o.b. Mt. Morris (bags returned).

Water.—Village water supply. Hydrants located at frequent intervals.

Old Macadam.—In order to fit the sidewalks about 900 cu. yd. old macadam will have to be excavated. This can be screened and reused as macadam bottom course between Sta. 0–26.

8. Comparative Cost Estimates.—The construction cost estimates are based on the equal strength depths recommended in article 6 of this report and on the material prices quoted in article 7 of this report. Labor at 35c. per hour.

The maintenance and renewal estimates are based on modified department records (see Table 24, page 141).

TABLE OF COMPARATIVE COSTS

1	2	3	4	5		6	7
Type	Location, Sta. to Sta.	Estimated construction cost per square yard	Interest on construction cost at 5 per cent	Maintenance and renewal yearly charges per square yard		Maintenance[1] of shoulders, culverts, ditches, etc., per square yard of pavement	Comparative total final yearly cost (sum of Columns 4, 5 and 6)
				Maintenance	Renewal		
Bituminous macadam	0–26	$1.60	$0.08	$0.040	$0.12	$0.005	$0.25
Bituminous macadam	26–48	1.90	0.095	0.050	0.18[2]	0.005	0.33
Reinforced cement concrete	0–48	2.70	0.135	0.010	0.16[2]	0.005	0.32
3-in. asphaltic concrete on 6-in. concrete base	26–48	3.10	0.155	0.025	0.17	0.005	0.35
4-in. brick ¾-in. cement sand cushion 5-in. concrete base	26–48	4.10	0.205	0.015	0.15	0.005	0.37

[1] Based on $100 per mile divided by the number of square yards of pavement in the job.

[2] Eventually sheet asphalt resurface.

The difference in Motor Operation Cost for the different types of surface (see Table, page 149) would not add over $0.02 per sq. yd. per year to the total yearly cost of Macadam as compared with Class A surfaces which brings the total estimated cost of the last column up to $0.27 for Bituminous Macadam Sta. 0–26.

From the standpoint of both original and final cost there is a very evident advantage for macadam Sta. 0–26. The local people have no particular preference as to type of pavement for this portion of the road. Local preference would be the only factor entitled to modify decisions based on the cost analysis provided the additional cost is paid locally. As this factor need not be considered we recommend bituminous macadam pavement from Sta. 0–26.

From Sta. 26 to 48 local preference must be considered. The village proposes to pay the additional cost introduced by such preference as to type and extra width desired. Under these conditions the cost analysis is of value only as indicating proper state cooperation. Article 10 gives alternate total estimates of cost to enable the village to come to a reasonable decision as to the type they will ask for.

9. Recommended State and County Cooperation Based on Final Cost, (Article 8).—The State would be justified in limiting their cooperation to the cost of a 16-ft. bituminous macadam pavement Sta. 0–26 and an 18-ft. reinforced concrete pavement Sta. 26–48 and 880 to 883+ with ordinary surface drainage

provisions. This would amount to approximately $35,000. This is not an excessive amount if the funds are available (see Table 3, page 22) considering the volume of traffic served. (About 1,500 daily.)

I understand that the rules of the Department limit cooperation to the construction of a 16-ft. road of the same type already constructed outside of the village. This rule would limit cooperation to a 16-ft. bituminous macadam which would cost approximately $30,000 for this locality. Under these circumstances it seems desirable to set the cooperation at $30,000.

10. Preliminary Cost Estimates.—The following estimates have been prepared to give the village authorities some basis for decision as to type and width. These estimates are rough preliminary figures subject to final revision after the plans are worked out in detail. They are, however, liberal and will in all probability exceed the final figures by from 10 to 15 per cent. Sidewalks, curbing and storm sewers are itemized separately to permit the village to estimate general and local charges. The pavement widths used have been tentatively approved by the Village Board and are listed as follows.:

Width, feet					
18 (no curb)	Sta.	0	to Sta.	16	
20 (no curb)	Sta.	16	to Sta.	26	
34 (curb)	Sta.	26	to Sta.	36	
34 to 60 (curb)	Sta.	36	to Sta.	39	
60 (curb)	Sta.	39	to Sta.	48	
40 (curb)	Sta.	880 + 37	to Sta.	883 + 66	±

A complete system of storm sewers is provided.

The unit prices for the major items are as follows:

ADOPTED UNIT PRICES

Excavation	$1.00 cu. yd.
Gravel subbase	2.20 cu. yd.
Macadam bottom (old macadam reused)	2.50 cu. yd.
Macadam bottom (new slag)	4.80 cu. yd.
Bituminous macadam top (limestone)	8.00 cu. yd.
Bituminous mat. A (penetration macadam)	0.12 gal.
7-in. reinforced cement concrete pavement	2.70 sq. yd.
3-in. asphaltic concrete on 6-in. cement concrete base	3.10 sq. yd.
4-in. brick, cement sand cushion, 5-in. cement concrete base	4.10 sq. yd.
Sidewalk	0.25 sq. ft.
Curb (concrete)	0.90 lin. ft.

ALTERNATE TOTAL ESTIMATES

Estimate 1. Bituminous macadam 10, 13 and 24 in. thick.

1. Excavation	$12,000
2. Curbing	6,000
3. Sidewalks	3,000
4. Special drainage	9,000
19,200 sq. yd. bituminous macadam pavement @ $1.90	36,000
Incidentals	3,000
	$69,000
State and county cooperation	30,000
Total village share	$39,000

Estimate 2.

Bituminous macadam Sta. 0–26.

Reinforced cement concrete Sta. 26–48 and Chapel St.

Items 1–4 (Estimate No. 1)	$30,000
13,600 sq. yd. reinforced concrete pavement @ $2.70	37,000
5,600 sq. yd. bituminous macadam @ $1.60	9,000
Incidentals	3,000
Total	$79,000
State and county	30,000
Total village share	$49,000

Estimate 3.

Bituminous macadam Sta. 0–26.

3-in. asphaltic concrete on 6-in. concrete base 26 to 48 and Chapel St.

Items 1–4 (Estimate No. 1)	$30,000
13,600 sq. yd. asphalt pavement @ $3.10	42,000
5,600 sq. yd. bituminous macadam @ $1.60	9,000
Incidentals	3,000
Total	$84,000
State and county cooperation	30,000
Total village share	$54,000

Estimate 4.

Bituminous macadam Sta. 0–26.

4-in. brick, cement sand cushion and 5-in. concrete base.

Items 1–4 (Estimate No. 1)	$30,000
13,600 sq. yd. brick pavement @ $4.10	56,000
5,600 sq. yd. bituminous macadam @ $1.60	9,000
Incidentals	3,000
Total	$98,000
State and county cooperation	30,000
Village total	$68,000

Signed W. G. Harger,
Designing Engineer.

Remarks.—For the interest of the reader actual procedure on this road was as follows. The contract was let for reinforced cement concrete pavement Sta. 0–26 and brick pavement Sta. 26–48 the local people paying the excess cost over and above the State Fund limit advised in the foregoing report. This was a rational solution considering local preference and willingness to assume added cost.

CHAPTER III

DETAILS OF DESIGN AND CONSTRUCTION

This chapter gives a concise description of the details of design and construction of various pavement types. Current practice is the best guide in these details as it represents accumulated practical experience under actual construction conditions. The interests of both engineers and material industries is identical in this phase of road work, namely, to utilize to the best advantage the material adopted. For this reason, current practice is clear cut and rational. The previous chapter emphasized the necessity of caution in accepting the arguments of non-technical current literature in regard to the selection of pavement type as in that phase of the problem, business and engineering interests often clash but after the type is once selected the procedure of construction is generally very good. There are a number of excellent books on the market which go into construction methods quite completely. We have no desire to duplicate in too much detail existing material and have therefore condensed this chapter to a brief statement of essentials. For the best up to date practical suggestions covering detail equipment and construction manipulation of standard materials, the student is referred to current publications obtainable free of charge from The Asphalt Association, New York City, The Portland Cement Association, Chicago, The Brick Manufacturers Association, Cleveland and other responsible Material and Equipment Organizations.

EARTH ROADS

Rut Roads.—The simplest form of road is the so-called rut road used in the arid regions of New Mexico and the southwest. They are constructed by clearing the right-of-way of brush and then cutting two shallow parallel ruts in the surface vegetation or soil crust by means of two cutting irons gaged to fit the ordinary wagon track. A wagon trail of this kind can be constructed for $10 to $30 per mile; can be used by autos with fair comfort at speeds up to 15 miles an hour and on the flat mesas of this district are more lasting and satisfactory than the ordinary turnpiked section as so little rain falls that an elevated fill grade does not consolidate and is worse than useless for traffic. On these rut roads any rain storms that occur wash the coarser particles of the soil into the ruts and gradually an armored track is formed below the general elevation of the mesa. No drainage structures are necessary where construction of this type is adopted.

Earth Roads.—The same principles of grade, section and drainage apply to this class of road as to the higher types except that the surface ditches are generally made slightly deeper and more care is taken with the underdrainage; this is necessary as the earth road becomes more

FIG. 53.—"Rut Roads" in New Mexico cost $10 to $20 per mile and very satisfactory for light travel up to speeds of 15 to 20 miles per hour.

easily saturated with water than types which are sealed over on the surface. If the natural soil is good road material such as gravel, disintegrated rock, hardpan or sandy loam this type of construction carefully

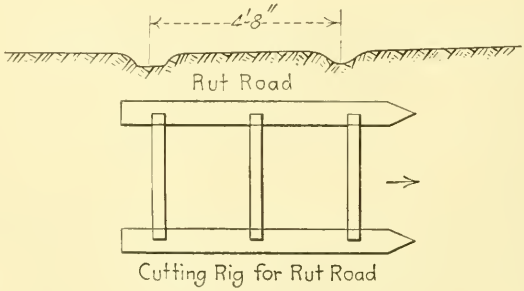


FIG. 54.—"Rut roads."

graded, drained and shaped by blader finish and maintained by dragging makes a satisfactory road for light traffic. Their cost depends on the amount of grading required and the methods that can be used. The

cost of drainage culverts, incidentals, etc., will vary but will run about $600 per mile for good work.

Simple blade machine turnpiking, where the dirt from the ditches made the center fill cost (in districts similar to Wyoming in 1914–1915) about $150 per mile. The same work at present (1918) is bid off for about $200 per mile. A fair relative price for first-class work of this kind including drainage and incidentals can be placed at $600 to $800 per mile.

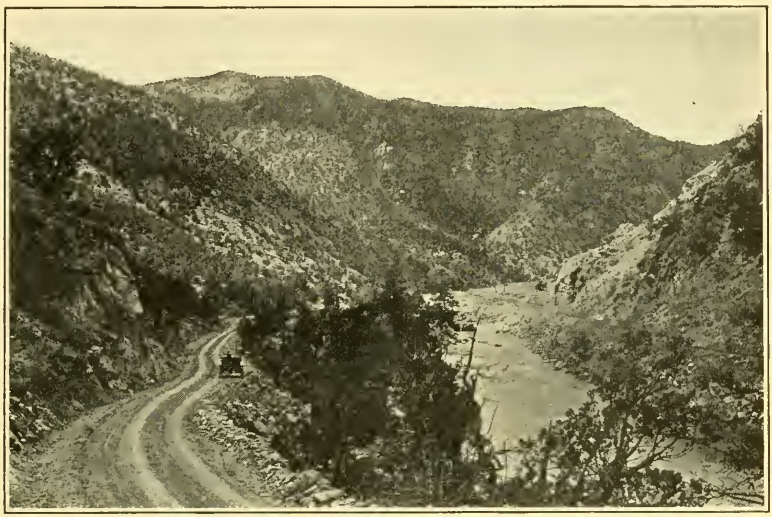


FIG. 55.—Good example of mountain natural soil road. Note the rock "wheel guard."

In rolling country requiring grade reductions by cut and fill and wagon haul a fair relative price including drainage and incidentals is approximately $2,000 to $4,000, where no rock is encountered.

In mountain road work where the excavation runs anywhere from 1,000 to 30,000 cu. yd. per mile with a large percentage of rock the cost will run anywhere from $1,000 per mile to $25,000 per mile. A fair average for such conditions is $5,000 to $8,000 per mile (1922 cost conditions).

As previously stated it is entirely a matter of required grading.

Current practice in earth road sections is shown in the following Figures:

Mountain roads..... Fig. 56, page 168
Iowa standards..... Fig .57, page 168
Pennsylvania standards..... Fig. 58, page 169

Current practice in grading and finishing are given in the following typical specifications:

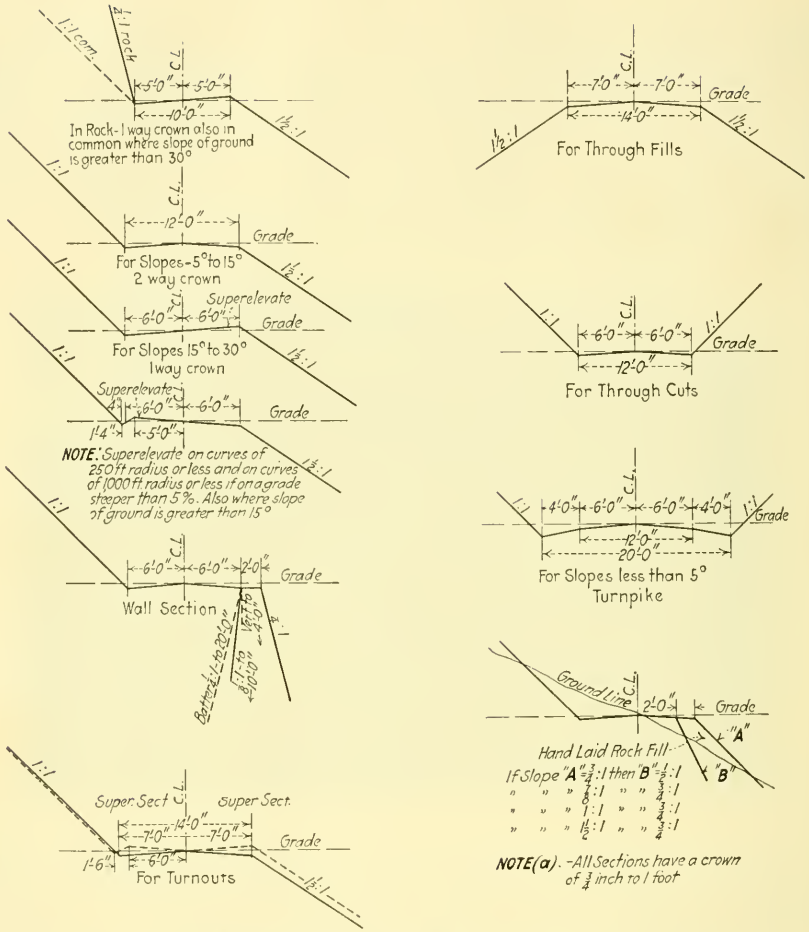

In Rock-1 way crown also in common where slope of ground is greater than 30°
For Slopes-5° to 15° 2 way crown
For Slopes 15° to 30° 1 way crown
NOTE: Superelevate on curves of 250 ft radius or less and on curves of 1000 ft radius or less if on a grade steeper than 5%. Also where slope of ground is greater than 15°
Wall Section
For Turnouts
For Through Fills
For Through Cuts
For Slopes less than 5° Turnpike
Hand Laid Rock Fill
NOTE(a). -All Sections have a crown of ¾ inch to 1 foot

FIG. 56.—U. S Bureau of Public Roads standard mountain earth road sections.

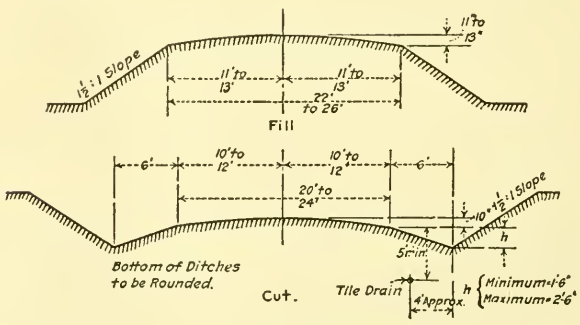


FIG. 57.—Typical earth road sections, State of Iowa.

Earth road maintenance is discussed in Chap. IV. The cost ranges from $20 to $200 per mile per year and for ordinary conditions probably averages about $50 to $100. Where it rises above these amounts a better grade of surface is generally constructed.

Where the soil is not a good road material the surface is improved by artificial mixtures of selected soil or by surfacing with gravel, chert, disintegrated granite, slag, shell cinders, etc., in fact any local material that gives body to the surface and prevents softening.

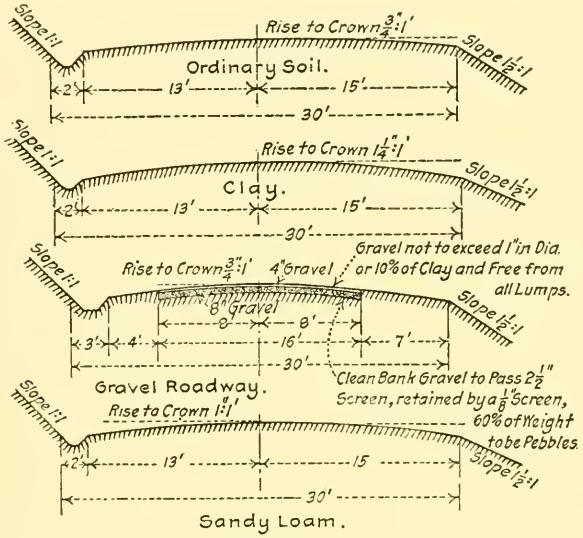


FIG. 58.—Typical earth and light gravel road sections, State of Pennsylvania.

STANDARD SPECIFICATIONS FOR EARTH AND GRAVEL ROAD CONSTRUCTION[1]

1. Alignment.—The center of the finished roadway shall conform in alignment to the center stakes. These stakes shall follow, as nearly as possible, the center line of the right-of-way.

2. Grade Lines.—The grade line shown on the profiles shall denote the crown of the finished roadway at its center line.

3. Cross-section.—Unless otherwise provided the cross-section to be used is the standard cross-section of the Highway Commission for the road system on which the work is located.

NOTE.—The Commission will approve changes in the standard cross-section to meet local conditions, on specific improvements, but a change approved for one road shall not be construed to apply to other roads. In each case the proposed change should be submitted to the district engineer who will make a field examination to determine the feasibility of the changes proposed.

4. Grading.—Under this head will be included all excavation and embankments required for the formation of the earth roadway, cutting all ditches along or contiguous to the road, forming the approaches to all side roads and farm entrances, changing of stream channels,

[1] Revised series of 1917, Iowa State Highway Commission.

and all other excavations and embankments connected with or incident to the construction of the road. Grading will be estimated under the following heads, *viz:*

Solid rock excavation.
Loose rock excavation.
Earth excavation.

Solid rock excavation will include all rock in masses which can not be removed without blasting, also all detached rock or boulders measuring not less than one cubic yard each.

Loose rock excavation will include all slate or other rock which can be quarried or removed without blasting, also all detached rock or boulders measuring not less than one-fourth nor more than 1 cu. yd. each.

Earth excavation will include all loose stones, boulders, and other material of every description as found, which are not included in the above specifications as solid and loose rock.

5. Excavation.—Excavation shall be made in all cases to the required alignment and cross-section. Any roots, stumps, or other timber encountered in the excavation shall be removed and burned or otherwise disposed of as directed by the engineer, but shall not be placed in the embankments. All materials taken from excavations shall be deposited in the embankments unless otherwise specified or directed by the engineer. The cost of moving the same when the average length of haul does not exceed 500 ft. will be considered as included in the price per cubic yard for excavation.

6. Provision for Drainage.—If it is necessary in the prosecution of the work to interrupt or obstruct the natural drainage of the surface, or the flow of artificial drains, the contractor shall provide for the same during the progress of the work in such a way that no damage shall result to either public or private interests. He shall then be held liable for all damages which may result from any neglect to provide for either natural or artificial drainage which he may have interrupted.

7. Intercepting Ditch.—In cuts along sidehills where there is a possibility of surface water causing damage by flowing down the side slope of the cut, a ditch shall be constructed to intercept the surface water and prevent it from flowing into the cut. The contractor will be paid for this work as an extra.

8. Borrow Pits.—When sufficient material for the embankments is not obtainable within the side ditches and excavations as staked out, the contractor shall make up the deficiency from borrow pits laid out by the engineer. Borrowing must be done from regular shaped borrow pits in order to admit of ready and accurate measurements, care being taken not to injure or disfigure the land unnecessarily. The banks must be sloped, the pits so constructed that surface water will drain out and the premises left in a condition satisfactory to the engineer. The right-of-way for borrow pits will be furnished by the county.

9. Berms.—Wherever it becomes necessary to make an excavation along the side of the road as in the construction of borrow pits, ditches, etc., a berm not less than 4 ft. in width shall be left between the toe of slope of the roadway embankment and the top of the excavation bank.

10. Waste.—When the amount of cut exceeds the amount of fill the excess material shall be deposited as directed by the engineer. Such material shall preferably be used in widening the adjacent fills so as to reduce the side slopes thereon.

11. Embankments.[1]—Embankments shall be carried up in horizontal layers, each of which shall be carried out to its proper width in the cross-section of the roadway. Sod obtained in the cuts may be deposited in the embankments provided it is so placed as to be not closer than 12 in. to the finished roadway or sub-grade. Stones obtained from cuts shall be so distributed in the embankments as to not form pockets or cavities. All existing slopes and surfaces of embankment shall be plowed where additional fill is to be made, so that the new material will bond with the old.

12. Guard Rail.—Where the height of an embankment is over 6 ft. substantial guard rails shall be constructed along the shoulders. Such guard rail will be paid for at the price bid per lineal foot of rail. Where the height of the embankment is 6 ft. or less, the side slopes shall be flattened to a slope not steeper than three to one (3 : 1) unless otherwise shown on the plans.

[1] This is a rather poor clause. See page 278 for better embankment practice for deep fills.

13. Sod in Blade Grader Work and Shallow Fills.—In blade grader work and in fills so shallow that the sod cannot be kept at least 12 in. below the finished roadway, such sod, after being cut loose with blade grade or plows, shall be disked and harrowed until it is reduced to small pieces which will not interfere with traffic. These small pieces of sod shall not be deposited in the middle of the road but shall be deposited near the shoulders and shall be covered with earth. The middle portion of the road shall be formed of earth free from sod. The disking and harrowing of sod is included in the price bid for excavation.

14. Side Ditches.—The side ditches shall be excavated to the depth, alignment, and cross-section shown on the drawings. Care shall be taken to secure a uniform grade on the ditches so that the water will readily drain out, and to secure smooth, uniform slopes on the ditch banks in strict conformance with the drawings.

15. Clearing and Grubbing.—The ground included in the highway must be cleared of trees, stumps, brush, weeds and grass to the full width of right-of-way, unless otherwise directed. All timber, stumps, brush, and other vegetable matter must be burned unless otherwise directed by the engineer. Such material shall not be placed in the embankments.

Where embankments are to be more than 2½ ft. in height, it will be sufficient to cut all trees, stumps, and brush close to the ground. Where embankments are to be less than 2½ ft. in height, and in all excavations, all stumps and large roots must be grubbed out and burned or removed.

Unless otherwise specified, clearing and grubbing will be paid for as extra work, as provided in Section 2, paragraph 22. Allowance will be made for all grubbing in excavations for the roadbed, all grubbing in borrow pits ordered and staked out by the engineer to supply material for the embankments, and all grubbing in embankments less than 2½ ft. high, but will not be allowed for embankments over 2½ ft. high, or in borrow pits made by the contractor without having been so ordered by the engineer.

16. Hedge Rows.—Hedges, under these specifications, are rows of trees or bushes, used for fence purposes or wind breaks, containing at least three bushes or trees per rod. For removing such hedges the contractor will be paid the price bid per rod.

17. Measurements.—Grading shall be estimated and paid for by the cubic yard at the prices specified in the tender. Measurements of grading quantities will, in all cases, be made from the cuts or pits from which the material is taken, by cross-sectioning before and after excavation, and the volumes determined by the average end area method.

18. Haul and Overhaul. —The average length of haul shall be determined by locating the center of gravity of the cut and the center of gravity of the corresponding fill. If the center of gravity of the cut is more than 500 ft. from the center of gravity of the corresponding fill, overhaul at the rate of one cent per cubic yard per 100 ft. will be allowed for the entire amount of material in the cut for the distance between the centers of gravity in excess of 500 ft.

NOTE.—Should the engineer desire to eliminate any payment for overhaul, a stipulation to that effect may be inserted in the instructions to bidders, as provided in Section 2, paragraph 25.

19. Tile Sub-drains.—Tile sub-drains shall be put in wherever shown on the plans. The tile used shall meet the requirements of the standard specifications for farm drain tile adopted in 1916 by the American Society for Testing Materials. The tile shall be laid true to grade and alignment established by the engineer. For furnishing and laying tile drains, the contractor will be paid at the price bid for such work.

NOTE.—The first requirement of road construction is to get a well-drained roadbed. For this reason, county engineers are instructed to require tile drainage on all portions of the highways where there is any question regarding the adequacy of the surface drainage or the stability of the soil.

If possible, the flow line of the tile shall be placed a minimum depth of 5 ft. below the elevation of the roadway shoulders. No tile less than 6 in. in diameter shall be specified.

Where the grade of the side ditch is less than 1 per cent., inlets to the tile shall be provided at intervals of about 500 ft. These inlets shall be constructed by filling the trench for a length of about 3 ft. with coarse gravel, broken stone, or other suitable porous material. The top of the porous material shall be raised about 8 in. above the top of the trench.

20. Finishing Stakes.—The engineer shall set suitable finishing stakes to guide the contractor in finishing the road.

NOTE.—One of the most common defects in earth road construction is the failure to bring the earth shoulders up to the proper grade and alignment. The shoulders are often left low and irregular, thus resulting in an unsightly road having too much crown in the center. This defect can be obviated only by setting stakes, giving the grade and alignment of the shoulders. In finishing, the contractor should use a templet to fit the crown of the road, and in this case stakes need be set only along one shoulder or along the center line. If no templet is used, finishing stakes should be set along each shoulder and on the center line.

Finishing stakes on fills should be set above the established grade so as to allow the proper amount of shrinkage. Under average conditions the following percentages for shrinkage should give satisfactory results:

DEPTH OF FILL	PERCENTAGE OF SHRINKAGE
Up to 5.0 ft	15
5.0 ft. to 12.0 ft	12
12.0 ft. to 18.0 ft	10

21. Finishing.—If the road is not to be surfaced with gravel, the contractor shall, after having brought it substantially to grade, complete the work in such a manner that the finished road will be smooth and true to cross-section, grade and alignment. No extra compensation will be allowed for finishing as this work must be included in the price bid for excavation.

If the road is to be surfaced with gravel, the earthwork necessary for forming the sub-grade shall be executed in the manner specified for the class of gravel surfacing to be used. The preparation of the sub-grade for the gravel surfacing is not included in the price bid for earthwork.

22. Installing Temporary Culverts.—Temporary culverts will be construed to mean corrugated culverts, boiler pipe culverts, concrete tile culverts, or cast-iron culverts not over 36 in. in diameter, and placed without permanent bulkheads. The county will furnish and deliver temporary culverts at the railroad station. The contractor will be required to haul, properly place, and fill over such culverts. For this he will be paid at the price bid per lineal foot.

SAND-CLAY ROADS

A poor earth road can be very materially improved by the so-called sand-clay surfacings. A well selected proportioning of sand and clay increases the resistance of a poor earth road both to traffic wear and to softening due to moisture. A sand-clay surface cannot of course be considered as a satisfactory all year round road for heavy loads but it is the easiest and cheapest means of increasing the ease and comfort of travel for a large part of the year and this type of road has had considerable popular approval particularly in the southern states. It is economically justified for light volume of traffic in financially poor districts where good road gravel is not available. Sand-clay construction is not advised in the northern states where gravel is available.

The cost of surfacing with sand-clay varies as any form of construction with labor, length of haul, cost of materials, etc., but generally adds from 15c. to 35c. per square yard to the cost of an earth road. A fair comparative figure would add $1,500 to $2,500 per mile for a 16 ft. width

of sand-clay to the cost of an ordinary dirt road in the same location (1922 cost conditions).

Sand-clay roads can not be considered as finished until traffic has used them for a year or two and all the small areas showing improper mix have been remedied by maintenance. The maintenance of sand-clay is

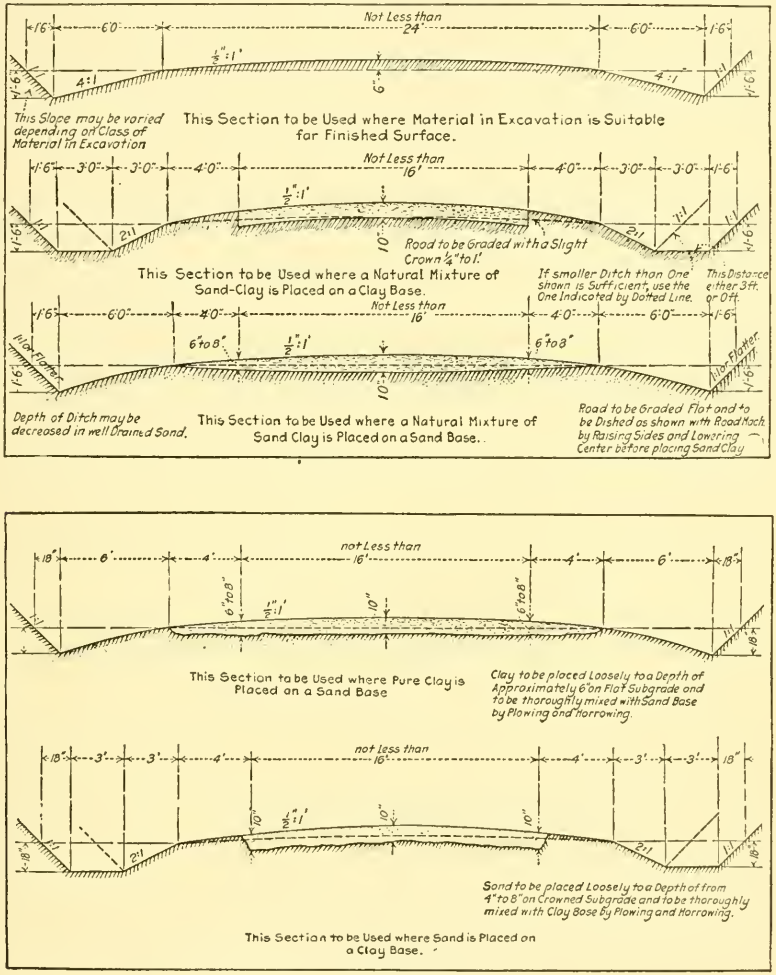

Not Less than
24'
6'-0"
1'-6"
1/2":1'
4:1
6"
This Slope may be varied depending on Class of Material in Excavation
This Section to be Used where Material in Excavation is Suitable for Finished Surface.
Not Less than
16'
4'-0"
3'-0"
1'-6"
2:1
1:1
10"
Road to be Graded with a Slight Crown 1/4" to 1'.
This Section to be Used where a Natural Mixture of Sand-Clay is Placed on a Clay Base.
If smaller Ditch than One shown is Sufficient, use the One Indicated by Dotted Line.
This Distance either 3ft. or 0ft.
6'-0"
6"to 8"
1/2":1'
1:1 Flatter.
Depth of Ditch may be decreased in well Drained Sand.
This Section to be Used where a Natural Mixture of Sand Clay is Placed on a Sand Base.
Road to be Graded Flat and to be Dished as shown with Road Hoch by Raising Sides and Lowering Center before placing Sand Clay
not Less than
16'
18"
6'
4'
This Section to be Used where Pure Clay is Placed on a Sand Base
Clay to be placed Loosely to a Depth of Approximately 6" on Flat Subgrade and to be thoroughly mixed with Sand Base by Plowing and Harrowing.
3'
Sand to be placed Loosely to a Depth of from 4" to 8" on Crowned Subgrade and to be thoroughly mixed with Clay Base By Plowing and Harrowing.
This Section to be Used where Sand is Placed on a Clay Base.

FIG. 59.—Typical sand clay road, State of Alabama.

discussed in Chap. IV and costs about the same as earth road maintenance. Specifications for sand-clay are given on page 177.

Proportioning of Soil Mixture.—Where the natural soil is clay the resisting power of the surface during wet weather can be increased by the

addition of sand. Where the natural soil is deep sand the surface can be made firm and resilient by the addition of clay. The so-called sand-clay treatment aims to provide a surface layer of mixed sand and clay about 10 to 12 in. deep (see Fig. 59, Alabama Standards) in which the sand forms the body and the clay just fills the voids in the sand and acts as a binder. It can be readily seen that different materials will require different proportioning of the sand and clay; the only sure way to get the best results is by experiment on the road during construction but to give an idea of the approximate proportioning the following list of recommended mixes is taken from the Good Roads Year Book of the American Highway Association, 1917.

The grains of which sand is composed are usually hard and tough and able to resist abrasion if held securely in place. In an asphalt pavement they are held by the asphalt and a wearing surface of great resistance to abrasion results. In a sand-clay road they are bound together by clay in a less firm manner but one giving excellent results on well-drained roads carrying light traffic. The aim of the builder of such a road is to employ just enough of the stickiest clay at his command to fill the pores of the sand and to mix these materials together so thoroughly that there are neither lumps or clay nor pockets of loose sand left in the surfacing. This gives the maximum amount of hard sand to carry the traffic and the minimum amount of clay to bind it. More sand makes a less durable road and more clay makes one which becomes soft more rapidly when wet.

There is a great difference in the value of different clays for such work. Some of them become dough-like when mixed with a certain amount of water and can be molded into objects which retain their shape after drying. If these molded objects are immersed in water they will retain their form for a long time. These varieties are called "plastic clays" and the most plastic are called "ball clays." There are other varieties which fall to pieces more or less quickly when wet, as quicklime does, and they are therefore called "slaking clays." They are more easily mixed with sand than the plastic clays but they have much less binding power and a road built with them is less durable when dry and more easily rutted when wet. The amount of clay to be used can be determined by a simple field test described as follows by Andrew P. Anderson:

From typical samples of each of the available clays, test mixtures, varying by one-half part, are made with the sand so that each clay is represented by a set of mixtures ranging by successive steps from one part sand and three parts clay to four parts sand and one part clay. These are worked up with water into a putty-like mass and from each mix two equal quantities are taken and rolled between the palms of the hands into reasonably true spheres, labeled and placed in the sun to dry. When thoroughly baked, a set of spheres representing any one clay is placed in a flat pan or dish and enough water poured gently into the pan to cover them, care being taken not to pour the water directly on the samples. Some samples will begin to disintegrate immediately. Those breaking down most slowly contain most nearly the proper proportion of sand and clay for the particular materials. The relative binding power of the various clays may then be determined by comparing the hardness and resistance to abrasion of the various dry samples having the correct proportion of sand and clay, as determined by the water tests.

In February, 1917, representatives of 21 state highway departments and of the U. S. Office of Public Roads recommended the following mixtures for hard, medium and soft classes of sand-clay roads.

Hard Class.—Clay, 9 to 15 per cent; silt, 5 to 15 per cent; total sand, 65 to 80 per cent; sand retained on a 60-mesh sieve, 45 to 60 per cent.

Medium Class.—Clay, 15 to 25 per cent; silt, 10 to 20 per cent; total sand, 60 to 70 per cent; and retained on a 60-mesh sieve, 30 to 45 per cent.

Soft Class.—Clay, 10 to 25 per cent; silt, 10 to 20 per cent; total sand, 55 to 80 per cent; sand retained on a 60-mesh sieve, 15 to 30 per cent.

By clay is meant material separated by subsidence through water and possessing plastic or adhesive properties; it is generally below 0.01 mm. in diameter. By silt is meant the fine material other than clay which passes a 200-mesh sieve and is generally from 0.07 to 0.01 mm. in diameter. By sand is meant the hard material which passes a 10-mesh and is retained on a 200-mesh sieve, and is generally from 1.85 to 0.07 mm. in diameter.

The larger part of the following explanation of the construction of sand-clay roads was prepared by W. S. Keller, State Engineer of Alabama, where many miles of sand-clay roads have been built and are giving good satisfaction:

Every farmer who lives in a section of country where both sand and clay are prevalent, is more than likely traveling over a section of natural sand-clay road but is ignorant of the fact. He can call to mind some particular spot on the road he travels though it may not be more than 100 ft. in length, that is always good and rarely requires the attention of the road hands. Good drainage will be noticed at this place and if he takes the trouble to investigate, he will find that a good mixture of sand and clay forms the wearing surface. If this 100 ft. of road is always good then the entire road can be made like it provided man will take advantage of the lesson taught by nature and grade the road so that the drainage will be good and surface the balance of the road with the same material. If it is not possible to find the ready mixed surfacing material convenient to the road it may be possible to find the two ingredients in close proximity. In case the road after grading shows an excess of sand, clay should be added, or in case clay predominates, sand should be added to produce good results. There are four general ways in which sand-clay roads may be built:

1. Ready mixed sand and clay placed on clay, sand or ordinary foundation.
2. Sand and clay placed on soil foundation and mixed.
3. Clay hauled on a sand foundation and mixed with the sand.
4. Sand hauled on a clay foundation and mixed with the clay. Taking up the various methods in order:

1. A natural mixture of sand and clay can often be found where the two materials are found separate. The most important point is to know the natural mixture when seen. The very best guide to this is to find a natural piece of good road. A sample from the best of this good section will, by comparison, indicate what is required, close to the road to be surfaced. This natural mixture of sand and clay can be noticed where red clay and sand crop out, usually well up in the hills, having ditches and cuts the appearance of red sandstone. A good stratum of well mixed sand and clay will stand perpendicular in cuts and ditches, resisting erosion almost as well as sandstone. A test of the best natural sand-clay mixtures will show the sand forms about 70 per cent of the whole. The test is very simple. Take an ordinary medicine glass, measure 2 oz. of the mixture into the glass and wash out the clay. Dry the remaining sand and measure again on the medicine glass. The loss will be the amount of clay originally contained in the mass.

Before placing any sand-clay on the road, the road should be graded to the desired width. The surface of the graded road should be flat or slightly convex. The sand-clay should be put on from 8 to 12 in. in thickness, depending on the character of the subgrade or foundation. With a hard clay for foundation, 8 in. of sand-clay will suffice. If the subgrade is sand it is well to put on as much as 12 in. of the surfacing material. After a few hundred feet of surfacing material has been placed, a grading machine should be run over it to smooth and crown the road surface before the top becomes hard and resists the cutting of the blade. It is a good plan to turn the blade of the machine so as to trim the edges of the surface part, discharging the excess sand and clay onto the earth shoulders. After one round trip with the blade turned out, the remaining dress work with the machine

should be with the blade turned in, with the exception of one trip down the center of road with the blade at right angles to the axis of the road for the purpose of distributing any excess of material left in the center.

After the machine work, it is well to follow with a drag, which smooths any rough places left by the machine and leaves the road with a smooth, even surface. A sand-clay road, unlike other roads, can not be finished in a short space of time. It can be left in an apparently finished condition with a hard smooth surface, but it will be found on close examination that the hard surface is in reality only a crust, below which there are several inches of loose material. After the first hard rain the crust softens, the road becomes bad and the work appears to be a failure. This, however, is just what is needed to make it eventually good. After the surface has dried until the mass is in a plastic state, it should be dragged until the surface is once more smooth, with proper crown, and should be kept this way by dragging at least once a day until the sun has baked it hard and firm. The mistake of keeping traffic off during this process of resetting should not be made. The continuous tamping of the wheels of wagons and hoofs of horses is just what is needed to compact the sand-clay into a homogeneous mass. The ordinary roller is not very effective in this work, but corrugated rollers have given excellent results. One type which is widely used has eighteen cast iron wheels weighing 300 lb. each, which compress the bottom of the mixture first. As the material becomes more and more compact the wheels ride higher and higher and finally the surface is so hard that the roller does not sink into it at all. A drag is an indispensable machine in the construction of any kind of sand-clay road.

2. Sand and clay placed on a soil foundation and mixed. This is necessary where the old road has neither a sand nor clay foundation and it is impossible to find the two ingredients ready mixed, but possible to get both in separate state near at hand. The clay should first be placed on the road to a depth of 4 in. and the required width. It is not wise to place more than a few hundred lineal feet of clay before the sand is hauled, as the clay rapidly hardens and makes the mixing process difficult. After, say, 400 ft. of clay have been placed, the clay should be broken by means of a plow and harrow, if it has become hard, and sand to a depth of 6 in. placed on it. This should be plowed and harrowed in thoroughly. This is best done immediately following a rain, as the two can be more satisfactorily mixed. The traffic aids the mixing and should be encouraged on the road. After the mass appears to be well mixed, the road should be properly shaped, as previously explained. The road should be given watchful attention and should sand or mud holes appear, a second plowing and mixing should be given it.

3. Clay hauled on a sand foundation and mixed with the sand. The mixing process is similar to that described under second head. It is only necessary to add that as the foundation is sand, a little more clay will be necessary than where the foundation is of clay or soil.

4. Sand hauled on a clay foundation and mixed with clay. The clay foundation should be plowed to a depth of 4 in. and harrowed with a disk or tooth harrow until the lumps are thoroughly broken or pulverized. Sand should then be added to a depth of 6 in. and mixed as before described.

Sand and clay can be mixed best when wet, but as most road construction is done in the summer months, it is necessary to do most of the mixing dry and keep the road in shape after the first two or three rains, while the passing wagons and vehicles give the road a final wet mixing. A sand-clay road is the cheapest road to maintain, for the reason that it can be repaired with its own material. With a drag or grading machine ruts can be filled with material scraped from the edges, whereas on gravel or macadam roads, this is not possible. The repairing of these roads can be done almost exclusively with the drag, only enough hand work being required to keep the gutters open and the growth of weeds cut on the shoulders. Holes are repaired by adding more sand-clay, and when many of them appear fresh sand-clay should be spread over the surface of the road. If the road gets into really bad condition, the road bed should be plowed up, reshaped and fresh sand-clay added. This is unnecessary where the road is maintained properly and the travel is not too heavy for the type of construction.

TOP SOIL OR SAND-CLAY SURFACE (ALABAMA STATE SPECIFICATIONS)

Description.—Upon the sub-grade, prepared as hereinbefore specified shall be constructed a top soil or sand-clay surface of the cross-section and compacted thickness shown on the plans.

Surfacing Material.—The surfacing material shall consist of top soil or natural sand-clay obtained from fields or pits designated by the engineer, and as near the right-of-way as practicable, or, in the event that it is impracticable to secure suitable top soil or natural mixed sand-clay, the surface shall consist of an artificial mixture of sand and clay, the materials for which artificial mixture shall be obtained from places designated by the engineer. Before any surfacing material is used it shall first have been approved by the engineer. The surfacing material shall be free from trash or other foreign matter and contain no stones or boulders that would fail to pass a one and one-half ($1\frac{1}{2}$) inch ring. Should any such non-road building material be placed on the road, it shall be removed by the contractor at his own expense.

The fields or pits from which the surfacing material is to be obtained will be furnished by the County free of charge to the contractor, but the contractor must provide and maintain at his own expense, all necessary roads for hauling the surfacing material to the road.

Construction Methods—Case 1.—Where the surfacing material consists of either top soil or natural sand-clay that has been approved for use without the admixture of any other material, it shall be evenly spread on the sub-grade to such depth that when compacted the surface will have the compacted thickness shown on the plans. The material shall be dumped on the sub-grade in longitudinal rows containing not more than one-third ($\frac{1}{3}$) of a cubic yard to 10 lin. ft. and the number of rows shall be such that when the material is spread, the desired cross-section and thickness of surface will be obtained. After sufficient material has been dumped in this way for one hundred or two hundred (100 or 200) feet of road surface, and before any part of the rows have commenced to pack, it shall be spread approximately to the required cross-section and harrowed to secure uniformity. The spreading may be done by hand or with a road machine in the following manner: 1. The machine shall be run over the road with the blade set so as to scrape off the tops of the piles and fill in the spaces between; 2. The outside edges shall be gone over with the blade set so as to pull the top soil or sand-clay toward the center; 3. The grading machine shall be run over the shoulders so as to pull the shoulder material up against the surfacing material and thus bring the entire road surface approximately to the required cross-section. The surfaced portion of the road shall then be harrowed with either a tooth or disc harrow until uniform density is secured, after which the road shall be brought to the required cross-section and so maintained until accepted. The shaping or reshaping of the surface shall be undertaken only when the weather conditions are such that the loosened surfacing or shoulder material will be readily compacted by traffic to form a well bonded surface.

Case 2.—When the surfacing material is to consist of an artificial mixture of sand and clay, made by mixing the material of the roadbed with sand or clay from some other source, the construction shall proceed in the following manner:

1. The surface of the road bed shall be thoroughly loosened by plowing and harrowing to a depth of from 4 to 8 in., according to the nature of the two materials to be mixed, and as the engineer may direct.

2. The material to be added shall be dumped and spread in the manner described for Case 1.

3. The added material shall be thoroughly mixed and incorporated with the material of the road bed. The mixing shall be done by means of plowing and harrowing and shall continue until the engineer is satisfied that the two materials are thoroughly mixed in proper proportion. A part of this mixing shall be done when the road is wet so that the surface will be puddled.

4. If, after mixing the two materials as above described, a deficiency of the added material is apparent at any point, such deficiency shall be immediately corrected by spreading more of the added material at that point and continuing the mixing as above described.

5. After the mixing is complete, as above specified, the road shall be shaped and maintained as provided in Case 1, except that wherever a poor mixture is observed, it shall be corrected by additional mixing or by adding necessary material and mixing.

Case 3.—When the surfacing material is to consist of an artificial mixture of sand and clay, both of which materials are to be obtained from without the road, the construction shall proceed in the following manner:

1. The materials shall be spread in successive layers on the road and mixed in place. The engineer will determine the order in which the two materials shall be spread, as well as the depth of layer for each material.

2. The dumping and spreading of the materials shall be done as specified for Case 1.

3. The mixing of the two materials and the shaping and maintaining of the road shall be done as specified for Case 2.

Basis of Payment.—The contract price per cubic yard for top soil or natural sand-clay surfacing material shall be full compensation for loosening, loading, spreading and harrowing, and for hauling the surfacing material one (1) mile or less, as well as for shaping and maintaining the surface true to cross-section until the road is accepted. In the case of an artificially mixed surface the materials brought on to the road will be paid for at the contract price per cubic yard for top soil or natural sand-clay surfacing material, which will include all the items mentioned above except harrowing, and the contract price per square yard for mixing will be full compensation for all necessary harrowing, plowing or other mixing. Measurement of all top soil or sand-clay surfacing materials will be made in trucks, wagons or cars, as it is delivered on the road, except that where the surfacing material is hauled in scrapers or shoveled on to the road, it will be measured compacted in place on the road.

Stripping of surfacing material pits will be paid for at the contract price for common excavation.

The bid price for overhaul of sand-clay will be allowed on all sand-clay materials necessarily hauled a distance greater than one (1) mile. The method of determining overhaul will be in all respects similar to that provided for determining overhaul in the case of crushed stone surfaces.

GRAVEL ROADS

A coarse well graded gravel is the most satisfactory material for a cheap year round road. It gives body to the traveled track, binds well, rides easily and with a consolidated depth of 8 in. to 20 in. holds all ordinary loads after it is well consolidated. For wheel pressures and depths of metaling see Chap. II, page 100.

Cost.—Pit run gravel varies in cost from $0.75 to $3.50 per consolidated cubic yard in place. Screened gravel from $1.50 to $4.00 per consolidated cubic yard. Gravel surfacing adds approximately $2,000 to $6,000 per mile to the cost of an earth road in the same location and a fair comparative price for this type including drainage and incidentals ranges from $4,000 to $10,000 per mile (1922 cost conditions). Maintenance is discussed in Chap. IV. The cost has a wide range from $100 to $600 depending on volume of traffic and degree of perfection of maintenance. As a general rule where the maintenance cost exceeds $400 to $600 per year it is advisable to build a better grade of pavement.

General Suitability.—At the present time 50 per cent of the mileage of surfaced roads in the U. S. are gravel roads. They are suitable for volumes of traffic up to 350 to 400 vehicles daily. Beyond this limit they often become very rough on account of so called rhythmic corrugations

which are difficult to control. Gravel has been utilized as a temporary expedient up to 2,000 to 3,000 vehicles daily but it cannot be advised for any such amount of traffic. Oiling with a light cold asphaltic oil or cold tar is resorted to under a moderately heavy automobile traffic. No gravel road should be oiled till at least a year old so that it is completely consolidated and firmly bound. The surface must be well cleaned of excess fine dust and the oil applied in two or three successive light coats of approximately ⅛ gal. per square yard at intervals of two or three months. It takes more than one application to give even moderately good results

FIG. 60.—Well built local gravel road in Western New York. Gravel 10 ft. wide. Very satisfactory for Class IV agricultural traffic, Note the shallow ditch which adds to the safety of traffic.

as the clay and loam in the road tends to prevent the formation of a good bond between the oil and gravel but if persistent treatment is adopted this method increases the power of gravel roads to withstand touring car traffic but of course does not increase their structural strength or make them suitable for heavy unit freight hauling. An official report on page 186 illustrates the economic use of gravel as compared with higher priced pavements for special conditions even on primary state highways.

Construction Essentials.—Gravel roads are hard to consolidate quickly and need carefully continuous attention to prevent the formation of ruts, holes or humps. They cannot be built by merely dumping loose gravel on the road and then hoping that traffic will put it in shape. A large mileage has been built on this principle and the results are shameful. A successful gravel road requires careful selection of the gravel, careful spreading, careful consolidation and constant maintenance. Current practice is shown in typical specifications pages 183 and 193; the essential features will be summarized at this point.

SIZE OF GRAVEL

Gravels suitable for road work are widely distributed over the country. They occur in bank deposits and in stream beds. The prime requisite of a gravel for foundation courses is that it contain a large percentage of coarse pebbles to give body and distribute the wheel loads. The prime requisite for a surfacing gravel is hardness of the stone and well graded coarse and fine particles which will take the wear evenly and bond well. Pit run gravel varies greatly as to size and composition even in a single pit and for this reason no definite limits can be well set for the proportion of sizing. In general it can be said that for foundation courses any coarse gravel, which when screened through a ¼-in. mesh contains less material passing the screen than retained on it, can be successfully manipulated without screening to remove the excess sand. In some localities this limit is not feasible on account of excessive fine material and the limit of fine material passing a ⅛-in. mesh is placed at 60 per cent but in reality a gravel of this fineness does not produce satisfactory results and a road on which it is used becomes more nearly a sand-clay construction than a gravel type. For a top course the large stone above 1½ in. in size should be screened out and if pit run is used the sand passing the ¼-in. mesh should not exceed 40 per cent of the volume. The most satisfactory top is a screened gravel but this adds materially to the cost. Where screened gravel is used ½ to 3 in. is satisfactory size for the bottom course and ½ to 1½ in. for the top course with a light surface wearing coat of sand and pea size up to ½ in. in diameter.[1]

The following specification has been recommended by the committee on Materials of the American Society of Civil Engineers.

Two mixtures of gravel, sand and clay shall be used, hereinafter designated in these specifications as No. 1 product (for top course) and No. 2 product (for middle and bottom courses).

No. 1 product shall consist of a mixture of gravel, sand and clay, with the proportions of the various sizes as follows: All to pass a 1½-in. screen and to have at least 60 and not more than 75 per cent retained on a ¼-in. screen; at least 25 and not more than 75 per cent of the total coarse aggregate (material over ¼ in. in size) to be retained on a ¾-in. screen; at least 65 per cent and not more than 85 per cent of the total aggregate (material under ¼ in. in size) to be retained on a 200-mesh sieve.

No. 2 product shall consist of a mixture of gravel, sand and clay, with the proportions of the various sizes as follows: All to pass a 2½-in. screen and to have at least 60 and not more than 75 per cent of the total coarse aggregate to be retained on a 1-in. screen, at least 65 and not more than 85 per cent of the total fine aggregate to be retained on a 200-mesh sieve.

Bonding Properties.—Clean gravel will not bond well. A small percentage of clay, loam or lime dust is desirable and necessary. This per cent ranges from 10 to 20 per cent. For bottom course, pit run gravel which contains over 20 per cent of clay or loam should not be used; from 10 to 15 per cent gives the best results. For top course 10 per cent is

[1] There is some tendency to reduce maximum size of top course gravel to 1¼ in. or even 1 in.

about the maximum clay or loam allowable particularly if it is to be treated with bitumen. Many so-called cementitious gravels of lime rock contain or produce under traffic a first-class rock dust binder of the highest grade. Clay or loam can be added to a clean gravel by mixing at the pit or by placing a thin layer of such material over the gravel as spread on the road and mixing it with the course during consolidation.

Spreading.—Gravel must be uniformly spread; there are two general methods; the trench spread (Fig. 61) and the feather edge spread (Figs. 62 and 63). The trench spread is not so likely to break down at the

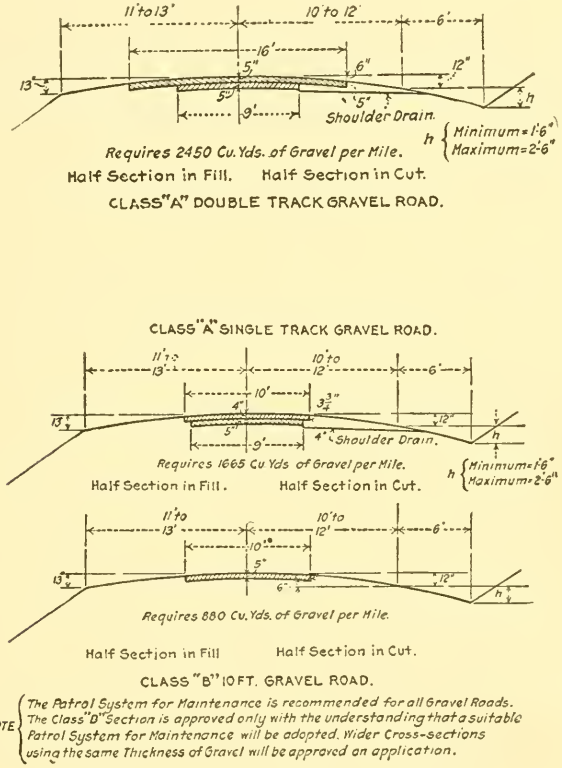


FIG. 61.—Iowa typical gravel roads.

edges as the feather edge but this can be remedied by a wider spread where the feather edge method is used. In either case the depth should be uniform and the surface properly crowned. Gravel should not be dumped in piles; it should be spread along in windrows or in sheets with Manger Spreader and the spreading finished by shoveling, raking or by road machine blade scrapers. If pit run gravel is used the course should be harrowed to distribute the sizes uniformly. The ratio of compacted to loose depth is approximately 1.2 or 1.25. That is a loose depth of

8 in. will compact to about 6½ in. If screened gravel is used the filler should be added before the course is rolled.

Consolidation.— Consolidation is the hardest feature of pit run gravel construction. Detail methods are described under gravel foundations,

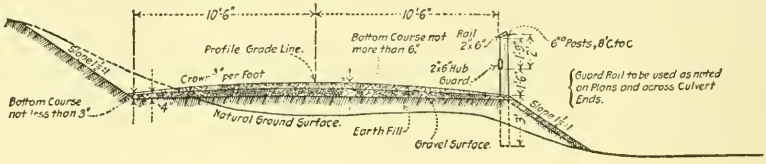


Fig. 62.—New Hampshire gravel road section.

page 196. A combination of traffic and roller consolidation while the gravel is moist gives the best and quickest consolidation although traffic alone will put it down firmly if given time and the shape is kept intact

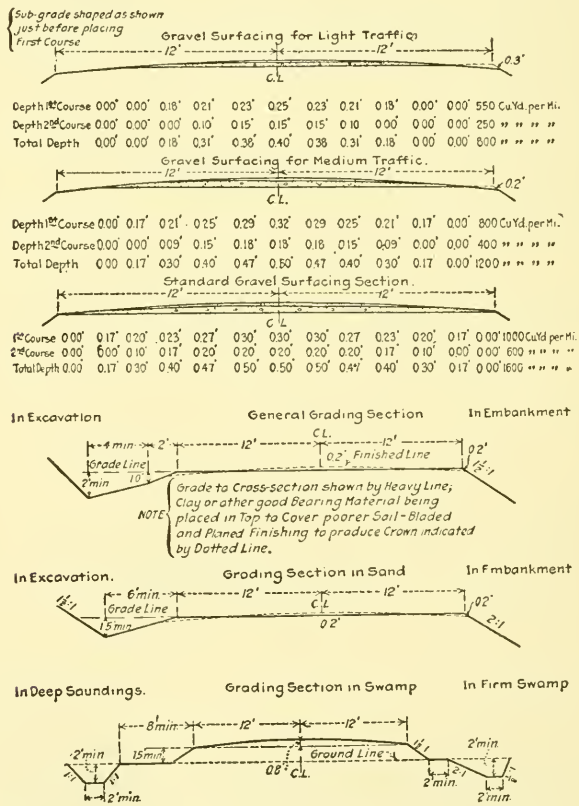

Sub-grade shaped as shown just before placing First Course
Gravel Surfacing for Light Traffic
12'
12'
0.3'
C.L.
Depth 1st Course 0.00' 0.00' 0.18' 0.21' 0.23' 0.25' 0.23' 0.21' 0.18' 0.00' 0.00' 550 Cu.Yd. per Mi.
Depth 2nd Course 0.00' 0.00' 0.00' 0.10' 0.15' 0.15' 0.15' 0.10 0.00' 0.00' 0.00' 250 " " " "
Total Depth 0.00' 0.00' 0.18' 0.31' 0.38' 0.40' 0.38 0.31' 0.18' 0.00' 0.00' 800 " " " "
Gravel Surfacing for Medium Traffic.
12'
12'
0.2'
C.L.
Depth 1st Course 0.00' 0.17' 0.21' 0.25' 0.29' 0.32' 0.29 0.25' 0.21' 0.17' 0.00' 800 Cu.Yd. per Mi.
Depth 2nd Course 0.00' 0.00' 0.09' 0.15' 0.18' 0.18' 0.18 0.15' 0.09' 0.00' 0.00' 400 " " " "
Total Depth 0.00 0.17' 0.30' 0.40' 0.47' 0.50' 0.47 0.40' 0.30' 0.17 0.00' 1200 " " " "
Standard Gravel Surfacing Section.
12'
12'
C.L.
1st Course 0.00' 0.17' 0.20' 0.23' 0.27' 0.30' 0.30' 0.30' 0.27 0.23' 0.20' 0.17' 0.00' 1000 Cu.Yd. per Mi.
2nd Course 0.00' 0.00' 0.10' 0.17' 0.20' 0.20' 0.20' 0.20' 0.17' 0.10' 0.00' 0.00' 600 " " " "
Total Depth 0.00 0.17' 0.30' 0.40' 0.47' 0.50' 0.50' 0.50' 0.47' 0.40' 0.30' 0.17' 0.00' 1600 " " " "
In Excavation
General Grading Section
In Embankment
4'min.
2'
12'
12'
C.L.
0.2' Finished Line
0.2'
1½:1
Grade Line
2'min
10'
NOTE
Grade to Cross-section shown by Heavy Line; Clay or other good Bearing Material being placed in Top to Cover poorer Soil - Bladed and Planed Finishing to produce Crown indicated by Dotted Line.
In Excavation.
Grading Section in Sand
In Embankment
1½:1
6'min.
12'
12'
0.2'
Grade Line
C.L.
1.5'min.
2:1
In Deep Soundings.
Grading Section in Swamp
In Firm Swamp
8'min.
12'
12'
2'min.
2'min
1½:1
15'min.
Ground Line
0.8'
C.L.
2:1
2'min.
2'min.
2'min.

Fig. 63.—Typical gravel road section, State of Minnesota.

by constant dragging with a hone or road machine. The Minnesota Specification page 183 shows the method employed where a road roller is not used.

MINNESOTA SPECIFICATIONS

Graveling

Description.—Graveling shall be construed to mean all surfacing with pit run gravel, screened gravel or crushed rock, or crushed rock screenings built in two or more successive courses.

Materials.—All materials shall be of a quality approved by the engineer and shall be the best obtainable from the specified pit or quarry. Materials for the first course shall contain no stone which would be retained on a screen having 2½ in. openings. Materials for the second course shall contain no stone which would be retained on a screen having 1 in. openings. If available material contains an excess of sand, such excess shall be handled as provided by special specification for each job or project.

Subgrade.—The cross-section of the subgrade shall be as shown on the standard cross-section accompanying the plans. Graveling upon a wet muddy road bed will not be permitted. If the graveling is not done in conjunction with the grading as a part of the same contract, the subgrade for the full length of job embraced in the graveling contract, shall, before being graveled, be dressed by the County to the cross-section above mentioned. Thereafter, the contractor shall keep it dressed to the specified cross-section and free from ruts, waves and undulations, as part of the graveling contract. If the grading and graveling are performed under the same contract, the preparation of the subgrade shall be performed as part of the grading item and no additional charge will be allowed therefor under the graveling.

Loading and Hauling.—Loading from pits shall be performed in such a manner and by such methods that a uniform grade of materials will not be delivered upon the road. Stone exceeding the sizes specified, shall not be loaded. No earth, sod or any foreign or vegetable matter, nor an excess of sand or clay, will be allowed in the gravel, and care must be taken that strippings be not mixed with the gravel. Any loads taken to the work containing such objectionable materials will be rejected.

Dumping and Spreading First Course.—The first course material shall be deposited in a uniform ridge on the center line of the road and shall be spread immediately upon the subgrade to a uniform section. This work shall be started at a point on the road nearest the pit or loading place and shall proceed therefrom until the extreme haul in that direction is reached.

Shaping and Compacting.—The resurfacing material shall be shaped, while being compacted under travel by the use of a blade grader, tooth harrow, planer or other suitable means. Ruts formed by the hauling or by travel shall be dragged full at least once each day and more frequently if necessary, to prevent cutting through the surfacing material into the subgrade. Holes, waves and undulations, which develop and are not filled by dragging shall be filled by adding more material according to the direction of the engineer. The shaping of the material shall be performed according to the direction of the engineer and shall be continued until the material is well compacted, free from ruts, waves and undulations and is made to conform to the cross-section indicated on the standard above mentioned.

If the material is not sufficiently compacted by the above methods within 20 days after placing, the engineer shall direct the character, amount and method of applying the binding material necessary to produce a compacted surface, and the contractor shall provide the necessary labor and equipment to perform such additional work at the unit prices submitted for the application of the regular surfacing material. The County shall furnish this binding material in the same manner as provided for the regular first and second course material.

Second Course.—When the first course is compacted and shaped as specified, to the satisfaction of the engineer, he shall authorize the application of the second course materials. It shall then be applied, shaped and compacted by the methods specified for the first course. The work of shaping and compacting shall be continued until the material is well compacted with the surfacing free from ruts, waves and undulations and conforming to the specified cross-section.

Other Coarse Materials.—The same principles apply to the use of any available local material such as slag, chert, caliche, disintegrated granite, cinders, shell, etc., each one of which can be used to advantage in special localities. A Specification for Chert follows:

CHERT SURFACE (ALABAMA STATE SPECIFICATIONS)

Description.—On the sub-grade, prepared as hereinbefore specified, shall be constructed a chert surface of the cross-section and compacted thickness shown on the plans.

Chert.—Before any chert is used in the construction of the road surface, it shall first have been approved by the Engineer. In general, the special provisions accompanying the proposal form will indicate the locations from which satisfactory chert may be obtained and also indicate whether crushing and screening of the chert will be required. Any large particle of chert that may be spread on the road, and that would fail to pass a 2-in. ring, shall be broken by hammering, or otherwise, before the surface is rolled. Unless otherwise provided in the special provisions, chert quarries will be furnished by the County free of charge to the contractor, but the contractor must provide and maintain roads to such quarries at his own expense.

Construction Methods.—The chert shall be spread on the sub-grade to such depth that when compacted the surface will have the compacted thickness shown on the plans. It shall be dumped, spread and rolled in the manner hereinbefore specified for dumping, spreading and rolling No. 1 and No. 2 crushed stone in the case of crushed stone surfaces. Where, in the judgment of the engineer, the conditions are such that a well bonded surface is not secured by rolling as above specified, the contractor shall sprinkle the surface with water while the rolling is in progress, and the sprinkling shall be done in such quantity and in such manner as the engineer may direct.

Basis of Pavement.—The contract price per cubic yard for chert for surfacing shall be full compensation for quarrying, crushing, loading, spreading, rolling, sprinkling, hauling the chert 1 mile or less, and maintaining the surface until the roads is accepted. Measurement of chert will be made in trucks, wagons, or cars as the chert is delivered. Stripping of chert quarries will be paid for at the contract price for common excavation. The bid price for overhaul of chert will be paid on all chert necessarily hauled a distance greater than 1 mile. The method of determining overhaul will be in all respects similar to that provided for determining overhaul in the case of crushed stone surfaces.

REPORT ON RHYTHMIC CORRUGATIONS BY GEO. E. LADD FOR U. S. OFFICE OF ROADS

Their Relation to Traffic.—Gravel roads subject to a traffic of not more than 200 or 300 cars per day remain practically free from corrugations, if occasionally dragged. As soon, however, as traffic reaches 400 to 450 cars per day corrugations develop very rapidly. In the State of Maine, where tourist traffic is large during the summer months, and its rate of increase is well known, the State Highway officials can predict almost to a day, when corrugations will begin to develop on certain roads. The traffic limitations of gravel roads in general are determined by the intensity of maintenance required and by its costs. Sufficient data have not yet been gathered on this subject. A Highway engineer's handbook covering the subject of gravel roads states that they are not fit for traffic exceeding 100 cars per day, but in Maine, Connecticut, New Hampshire, and other states, they are successfully serving a traffic of from 700 to several thousand cars per day. In Wisconsin, gravel roads are maintained with comparatively smooth surface so that auto travel is comfortable and satisfactory on roads serving from 1,800 to 3,200 cars per day with a maintenance cost ranging from $280 to $320 per year, or from $600 to $700 per year when the roads are also treated with dust preventives.

Maintenance costs on gravel roads in various states have been reported to the writer as ranging from $1,000 to $3,000 per year. No satisfactory analyses of such costs have been made and it is presumed that a considerable portion of them really belong to improvement and reconstruction.

The Relation of Rhythmic Corrugations to Kinds of Gravel Mix and Methods of Construction.—The fact that these corrugations are so general and occur in all sections of the United States makes it evident that nearly all gravel roads are subject to the development of this nuisance and menace, if they serve sufficient traffic, although the methods of construction and kinds of gravel vary widely. The situation, however, is not hopeless. Several highway officials have expressed the opinion that less corrugation trouble is found where the gravel is angular than where it is composed of highly rounded particles. It is also claimed that where the road is constructed of gravel more uniform in size than pit run, and especially where everything over 1 in. is excluded, that corrugations are slower in developing and more easily eliminated by maintenance methods. In northern New Hampshire some roads are built of so-called gravel which has resulted from the decomposition of granite rocks and is full of angular quartz. The roads built of this material are said to give better service so far as corrugations are concerned than those, built in the same state, of glacial gravels, or those resulting from disintegration of schistose rock. It is claimed in Wisconsin that the best service given by gravel roads, so far as corrugations are concerned, is found where pit run gravel is passed through a crusher and the material only used which ranges in size from 1 in. down. Highway engineers, notably some in Wisconsin, and in Oregon, object to any clay binder in the gravel and prefer only the fines produced by crushing, and such as result from surface wear.

During the writer's investigations in the state of Maine it was noted that roads with a relatively high per cent of clay-silt binder were comparatively free from corrugations. On one road on which rhythmic corrugations were well developed a patch near the center of the road, about 70 ft. long and varying from 1 to 4 ft in width, was uncrossed by corrugations, and had a hard, smooth surface. Examination showed that this patch had about 5 per cent more clay-silt bond than the surrounding road.

On the gravel road between Waterville and Bangor corrugations develop rapidly during the summer traffic, and are kept down only by constant maintenance for almost its entire length. Comfortable travel on this road was made possible only by continuous use of drags and planers. One short section of the road, however, was practically free from corrugations throughout the summer. This section was built of a softer gravel, which was high in clay-silt bond. Unfortunately, though, while this section of road gives satisfaction during the summer months, it is said to be nearly impassable in the spring. Thus it may be that an all-year gravel road that will not require intensive maintenance cannot be built in states subject to heavy freezing and wet seasons.

This problem remains for future solution and must be worked out by a combination of field observations and laboratory tests. In this connection it may be stated that the present standard tests of gravel are unsatisfactory in that they do not include determination of the nature and qualities of natural binder originally in the gravel. The so-called cementing value test has to do only with the products of abrasion of individual gravel particles. While it is important to determine this factor, there must also be a determination, in addition to the facts brought out by mechanical analyses as to the quantity of clay-silt binder, of the cementing value of this fine material. The writer is now engaged in experiments connected with the testing of different mixtures of gravel, sand and clay-silt binders, and their behavior under different degrees of compacting and with different amounts of water present. In future investigations observations must be made over a wide area and under varying conditions as to the relation between the amount and kind of natural binder in the road and the behavior of the road under traffic. Another interesting problem in this connection is the question of migration of clay binders toward the surface, and their ultimate loss to the road through the combination of rain, wind and traffic influences.

The Effect of Dust Preventives and Surface Binders.—A preliminary study has been made of problems of surface treated gravel roads. Matters of methods, costs and service have been studied to some extent in certain states. Surface binders in a general way prevent development of corrugations, and where these do occur on binder-treated roads, it has been demonstrated that they result from excessive quantities of bituminous material. This statement does not refer to dust-prevention treatment, and is perhaps not true of glutrin-treated roads. Some states use both tar and oil binders, some will use only oil and others only tar. One state, at least, uses glutrin almost exclusively. Dust preventives have been seen to fulfil the primary requirement. Their effect on corrugations, however, is not yet clear. It is not unlikely that they delay the development of rhythmic corrugations

of the first type discussed above. It is clear, however, that they do not prevent their development. They successfully lay dust for long periods, in spite of heavy traffic, and they lengthen the life of a road by retarding loss of surface material.

Maintenance Methods.[1]—The maintenance required by a gravel road depends, of course, largely upon the amount of traffic to which it is subjected. If this does not exceed 200 or 300 cars per day, occasional dragging, especially after rains, will keep the surface in good condition. As traffic increases, however, surface maintenance must be practically continuous, and even then dragging or scraping will not keep a road free from corrugations. The planer, a simple machine familiar to all highway engineers, is employed in addition to the drag and road scraper. Planers[2] are of different types. Those used in some states have a single cutting blade, while those used in other states have several shorter blades so arranged as not only to cut down corrugations but to distribute and rearrange the surface materials. Apparently, the best machine for eliminating corrugations has not been devised. The planer certainly does not always entirely remove them, some of the bases of ridges being left so that traffic may, in 24 hours after the planing of the road, reproduce the corrugations in original form and position. Even resurfacing with 1½ to 2 in. of gravel, following planing of the road, will not prevent the immediate recurrence of corrugations which have not been *entirely* eliminated by planing and dragging. In Wisconsin some gravel roads subject to heavy traffic are scarified once or twice during the summer months, and left to be recompacted by traffic. This is heroic treatment. Experiments are contemplated for this coming field season which may lead to improving maintenance methods, so far as corrugations are concerned. The whole subject of maintenance of gravel roads, and its cost and economic significance will be discussed in another paper.

SAMPLE OFFICIAL DESIGN REPORT

Recommending Gravel Pavement Construction on Class III Traffic Primary State Highway

The following condensed report shows a case where gravel construction was recommended on a primary State Road. This report refers to the road discussed in Appendix "B," pages 581 to 596:

FEDERAL AID PROJECT NO. 184 WOODVILLE—BRISTOL SPRINGS—CHESHIRE

Alternate Estimates.—Three alternate estimates are submitted. Any of these will serve the purpose and each has certain desirable features.

First Reinforced Cement Concrete 7-, 6-, and 7-in. Mesh and Bar.—This design is estimated at $620,000 or an increase of approximately $154,000 over the estimate of August 1922. Approximately $36,000 of this increase is due to relocation changes requested by the Office of Public Roads. Approximately $118,000 of the increase is due to change in Pavement Thickness, Guard Rail Type, Culvert Improvements and Increase in Unit Prices.

This design will satisfy the Office of Public Roads but will not satisfy the local authorities, due to large increase in cost.

As per our previous correspondence, there is some doubt as to the advisability of attempting to construct a Concrete Pavement on the fresh high fills and new side hill grading, Sta. 0–240, for a series of short breaks aggregating from 3,000 to 7,000 lin. ft. as per list attached to alternate Typical Section.

Second Estimate Oiled Gravel Pavement.—This design is estimated at $450,000 as compared with the August estimate of $466,000. This design is based on a 13-in. Oiled Gravel Pavement with extra subbase for the entire length of the road. It also used Guide Posts as per original estimate on straight alignment.

This design will satisfy the Office of Public Roads and the local authorities. It will increase the yearly maintenance charge for the first few years until recapped, but considering

[1] Mr. Ladd's report bears out our local experience that maintenance costs increase very rapidly where the volume of traffic exceeds 450 to 500 daily average.

[2] See page 450, Chap. IV.

the volume of traffic, this will not be beyond the bounds of reason, as indicated by our Maintenance records for this type under light traffic. This design seems to be the most rational solution for this particular road considering all the factors involved namely: high cost of grading impossible to eliminate and still get the approval of the U. S. Bureau; second, limited local funds; third, economy of final cost as compared with Concrete Pavement Construction.

Third Estimate Combination of Concrete and Oiled Gravel.—This design is estimated at $584,000 or an increase in cost of $118,000 over the estimate of August, 1922. This design substitutes a 13-in. Oiled Gravel Pavement for Cement Concrete on the doubtful grading sections of the road. It also used Guide Posts in place of Cable Rail on straight alignment.

This design will satisfy the Office of Public Roads and may serve as a compromise solution with the local authorities provided the Department desires to use concrete on this road.

Pavement Type.—This road is isolated from Railroad shipping points and imported materials would be prohibitive in cost. There is a limited amount of local boulder stone 7,000 to 10,000 cu. yd. widely scattered and difficult to collect, Sta. 240–519. This stone is suitable for boulder base. There is one good gravel pit of unlimited capacity on road (Long's pit, 1,600 ft. from Sta. 140). This gravel is suitable for gravel foundations and screened gravel top course and if washed for cement concrete pavement. This gravel seems to be the most feasible source of supply. Alternate estimates have been prepared for cement concrete pavement 7, 6, 7 in. costing approximate $3.40 per square yard and for a 13-in. oiled gravel pavement costing approximately $1.50 per square yard. There are 86,000 sq. yd. of pavement on this job.

Cement Concrete 7, 6, 7 in.
Mesh and Bar
Cost per Square Yard

0.18518 cu. yd. concrete @ 7.90	$1.46
0.3518 bbl. cement @ 3.90	1.37
9 sq. ft. mesh @ 0.055	0.50
2.81 lb. bars @ 0.036	0.10
	$3.43

86,000 sq. yd. × $3.40—$292,400
Average maintenance $0.008 per square yard.
Class III traffic (less than 500 vehicles daily)

Gravel Pavement Oiled
13-in. Depth
6, 4, 3 in.
Cost per Square Yard

0.278 cu. yd. pit run foundation @ $3.40	$0.95
0.083 cu. yd. screened top @ 5.20	0.43
0.37 gal. oil @ 0.15	0.06
3 lb. calcium chloride @ 0.012	0.04
	$1.48

86,000 × 1.50 = $129,000
Average maintenance $0.065
Class III traffic (less than 500 vehicles daily). Under these conditions the gravel pavement seems to be a desirable solution.

W. G. HARGER,
Designing Engineer.

Miscellaneous Special Cases.—Alaskan climatic and soil requirements afford special problems; the following quotation from *Engineering and Contracting* of March 6, 1918, indicates an interesting condition as described in the report of the Alaskan Highway Commission:

The most unusual and troublesome feature encountered in construction is the permanently frozen ground which covers a large portion of the entire interior, and which is protected from thawing during the summer by a thick layer of moss, turf, or decayed vegetable matter. The character of this frozen material varies largely in different sections of the territory, and even in the same section. It may be gravel, clay, silt, peat, or clear ice or a combination of two or more of these elements.

When gravel is encountered the problem presents no special difficulties; the moss or turf is stripped off, and the road graded in the usual manner. When the material is clay, experience has shown that the same procedure can usually be followed, but the grading is a slow and rather expensive process. After the protective covering of vegetable matter is removed, it is necessary to allow the soil to thaw and dry out somewhat before it can be worked, and unless a considerable period is allowed to elapse between the stripping and the grading, it will be found that the thawing is not extended to sufficient depth to permit of completing the grading in one operation. When the necessity for the road is not pressing, an appreciable saving can be effected by stripping the roadbed and digging drainage ditches during one season, completing the construction the next year.

In those localities, however, where the frozen material is silt or peat, the stripping of the road bed quickly results in the formation of a quagmire through which a man or horse, even without a load, can pass only with the greatest difficulty. Such soil has sufficient bearing value only as long as it remains frozen, which makes it desirable that the moss or turf overlying it be kept intact. This layer of vegetable matter is not of itself able to sustain traffic, necessitating the addition of a protective covering—usually of scrub spruce timber which covers a large part of interior Alaska, except the Seward Peninsula, and affords excellent material for this corduroy.

Where the trees are large enough pole corduroy is constructed by grubbing all stumps and roots from the road bed, leveling it, and laying perpendicularly to the axis of the road a single layer of poles from which the largest and stiffest branches have been trimmed. Ditches are then dug at a distance of 3 to 5 ft. from the ends of the poles, and the material therefrom, after rejecting the top layer of vegetable matter, is placed on the corduroy for the double purpose of protecting it from wear and affording a smoother roadway. If the soil in the ditches is entirely unsuitable for this covering, other material, preferably gravel, is hauled on from the nearest available source.

Where the spruce timber is of very small size, or where only small willows are available, as on the Seward Peninsula, brush corduroy is used. The method of construction is similar to that described above, except that the single layer of poles is replaced by a mattress of untrimmed brush containing sufficient material to give a thickness of at least 6 in. when compressed.

When corduroy has been properly protected, its life in most parts of Alaska is quite long. Poles taken out of the road after 10 years of service have been found to be in excellent condition.

The 3- to 5-ft. berm which is left between the ends of the corduroy and the ditches is very necessary to protect the corduroy from undermining, as the ditches, under the action of sun and rain, slough and cut rapidly. Ordinarily, as the frozen soil thaws and cuts away the moss, the berm gradually assumes a gentle slope to the bottom of the ditch, effectually protecting the corduroy, but where the cutting is severe, it often becomes necessary to revet the insides of the ditches with moss or turf. Frequent outlets from the ditches must be provided, and when the amount of water reaching the ditch on the upper side of the road is large it is advisable to construct an additional ditch parallel to the road and about 50 ft. away, with sufficient outlets to culverts of ample size.

Along the Pacific coast of Alaska no frozen ground is encountered, but the mountainous character of the country, the excessive rainfall, and the difficulties of clearing, have made the work, as a rule, even more expensive than in the interior. Unless the soil encountered in this region is gravel, it will not stand up under traffic during the heavy and continuous rains, and some protective covering is required. Fortunately gravel is usually found at no great distance; otherwise corduroy or plank roads are constructed.

The numerous swift streams of glacial origin found in the Pacific coast section and throughout the Alaskan range in the interior have been the source of much trouble and expense. Flowing through gravel beds varying in width with the volume of water carried up to 2 miles or more, they rarely have any fixed channels. It is by no means uncommon

for one of these streams to abandon an old channel and establish itself in a new one ½ mile away almost over night. When warm weather causes rapid melting of snow and ice in the glaciers, these streams become raging torrents of enormous destructive force, and roads paralleling them are in constant danger of being washed away. Numerous methods of bank protection to prevent damage from this cause have been tried, of which the following has proved to be the cheapest and most effective. A layer of loose brush of sufficient length to give the requisite protection is placed on the threatened bank, perpendicular to the current and weighted below the center with stone enveloped in galvanized-wire netting, the whole being anchored in place by wires extending to "dead-men." For emergency work when the water is too high to permit of placing the wire netting and rock, the brush is made into fascines inclosing sacks of earth, which are then placed against the threatened bank and wired to it and to each other. This form of protection is easily and quickly constructed and has repeatedly demonstrated its effectiveness.

As now constructed, the width of wagon roads varies with the formation of the ground and the amount of traffic expected, but as a general rule roads graded by other means than the road grader are given a minimum width of 20 ft. between ditches, and those on which the grader is used a minimum width of 24 ft. On steep sidehills and where rock work is involved, the width is reduced to 10 or 12 ft. The standard width of clearing is 30 ft. but this is is increased to 60 ft. where necessary in order to secure the beneficial action of wind and sun on the road bed.

Sled roads for winter traffic only are cleared for a width of 16 ft., with all stumps, hummocks and similar obstacles removed for a width of 8 ft. They are constructed where the amount of traffic is not large enough to justify a wagon road, where the cost of building a wagon road would be prohibitive, or where the communities along the route are amply served by water transportation during the open season, as is the case with the Fairbanks-Fort Gibbon sled road. If it seems probable that future development may demand or justify a wagon road, the location is made as for a wagon road, in order that work done on the sled road may be of use when the improvement is made.

Trails designed for travel by dog team in winter or by pack train in summer are given a width of 8 ft. with all stumps and underbrush cut off as close to the ground as possible.

In the past, the work of constructing and gradually improving the roads has been so generally intermingled with maintenance operations that a systematic plan for maintenance has not been put into effect, nor would such a plan have been feasible in view of the uncompleted state of the roads. At the present time, however, the condition of parts of the more important roads, notably the Valdez-Fairbanks Road, is such as to make practicable their maintenance by dragging. As Alaska has only a very small agricultural population, the method adopted in many states of contracting with farmers adjacent to the road for the necessary dragging cannot be used, but it is intended to place on completed sections small maintenance crews consisting, as a rule, of two men each, supplied with a team, wagon, drag, and the necessary small tools. Two such crews have been employed on the Valdez-Fairbanks Road during the present summer, with very satisfactory results. On several of the gravel-surfaced roads in southeastern Alaska the patrol system of maintenance has been used in connection with more extensive repairs. The results show the method to be very effective for roads of this character.

The average costs per mile, including construction and maintenance of all roads and trails constructed by the board since its organization in 1905 are as follows: Wagon road, $3,419; sled road, $379; trail, $113. A division of these amounts to show the exact cost of construction proper is impossible, but a careful analysis of the available data indicates that the following unit costs of construction, including bridges, may be accepted as approximately correct: Wagon roads, $2,475 per mile; sled roads, $300 per mile; trails, $65 per mile. The average costs of maintenance during the past season were as follows: Wagon roads, $250 per mile; sled roads, $41 per mile; trails, $8 per mile.

Arid Regions.—In the arid regions fills must be avoided. Ordinary earth roads are constructed below the general elevation of the ground which keeps them moist longer (see accompanying illustrations); shallow ditches are used for the same reason. In many cases a hardpan forma-

tion underlies the sand surface and in these conditions the sand surface is scraped off and the road built on the underlying strata.

Where fills must be used they should be made during the rainy season and the addition of clay to a sandy soil helps consolidate the traveled way. Readers are referred to the reports of the State Engineers of New

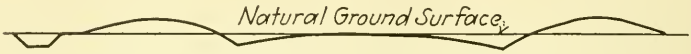


FIG. 64.—Roadbed below natural ground elevation.

Mexico and Arizona for further data on the special treatment of roads under these conditions.

Summary.—Roads of the type discussed in the preceding part of this chapter form the groundwork of future high-class pavements and

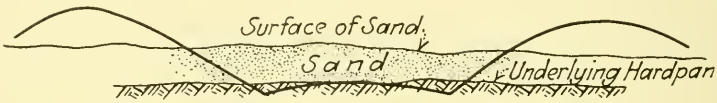


FIG. 64A.—Roadbed on underlying hard formation.

represent the greater percentage of mileage of roads in this country. They are entitled to more engineering supervision than they have received in the past. That is they should be improved by a series of well thought out related steps of progressive improvement (see page 7).

STONE AND GRAVEL FOUNDATION COURSES FOR FLEXIBLE TYPE PAVEMENTS

Preparation of Subgrade.—It is evident from the pressures to which a road is subjected that the subgrade must be well consolidated before placing the foundation stone. This is usually effected by rolling with a 10- or 15-ton steam roller, exerting a pressure of 350 to 500 lb. per linear inch or wheel width, and is continued until the grade is firm and compact.

The difficulties of consolidation in different soils and the methods of overcoming them are discussed under Inspection, pages 224 and 225.

Kinds of Foundation Courses.—The foundation courses in ordinary use are as follows:

1. Crushed stone.
2. Screened gravel.
3. Field stone subbase.
4. Pit gravel subbase.
5. Field stone subbase bottom course.
6. Pit gravel subbase bottom course.
7. Quarry stone base or Telford.

1. Broken Stone Bottom Course.—This style of construction is the one in most general use. Where local stone is abundant and well distributed, such a course will cost[1] from $3.50 to $5 per cubic yard rolled in place; where imported stone is necessary, the cost depends largely upon the freight rate and the length of haul and may run as high as $7. Bottom of this kind is generally used where the total depth of stone metalling does not exceed 6 to 8 in. after rolling. Beyond these depths it is often cheaper to substitute subbase or subbase bottom course for a part or the whole of the broken stone course.

The method of construction by the New York State Highway Commission is shown in the following extract from the 1920 specifications:

BOTTOM COURSE

ITEM 44—BOTTOM COURSE—SCREENED GRAVEL
ITEM 45—BOTTOM COURSE—BROKEN STONE
ITEM 45A—BOTTOM COURSE—BROKEN SLAG

Work. 44.1. Under these items the Contractor shall furnish and place stone, slag or gravel, conforming to the general requirements for same, either upon the properly prepared subgrade or upon the foundation course. This stone, slag or gravel shall be of sizes specified below.

[1] All costs are for comparative purposes and are based on 1922 conditions.

Material. 44.2. After the subgrade or foundation course shall have been properly prepared and proper drainage provided, a course of broken stone, broken slag or gravel of graded No. 4 or a uniform mixture of No. 3 and No. 4 shall be spread evenly so that it will have after rolling the required thickness. One inch of No. 2 stone, slag or gravel may be used in the bottom course if placed on the foundation and will be considered a part of the course.[1]

In cases where the finished thickness of the bottom course is to be more than 5 in., the broken stone, broken slag or gravel for it shall be spread, rolled and filled in two separate layers neither of which shall be of a greater depth than 6 in. measured loose.

Gaging blocks. 44.3. The depth of loose stone, slag or gravel in all cases shall be gaged by the use of cubical blocks of suitable size.

Dumping on roadway. 44.4. The spreading of any layer or course of broken stone, broken slag, gravel or filler, whether in foundation, bottom or top courses, shall be done from suitable spreader wagons or from piles dumped along the road as directed by the Engineer.

No segregation of large or fine particles will be allowed, but the stone, slag or gravel as spread shall be well graded with no pockets of fine material.

Rolling and filling. 44.5. After the bottom course of stone, slag or gravel has been laid loose it shall be thoroughly rolled with an approved roller weighing not less than 10 tons.

This rolling must begin at the sides and continue toward the center and shall continue until there is no movement of the stone or slag ahead of the roller. After the stone or slag is thoroughly compacted No. 1 stone, slag or gravel, and screenings or sand, or a mixture of these, shall be uniformly spread upon the surface and swept in with rattan or steel brooms and rolled dry. After the completion of the rolling no teaming other than that necessary for bringing material for the next course shall be allowed over the rolled material. It is the intention to bind this course with the small stone or slag but no surplus of filler will be allowed on this course. This course should not be laid in excess of 500 lin. ft. without being rolled and thoroughly filled so as to render it waterproof and thereby prevent the softening up of the subgrade.

In case of two courses. 44.6. When two courses of bottom stone or slag are laid each course shall be treated by rolling and adding fine material as described above.

Replacing. 44.7. If the subgrade material shall become churned up into or mixed with the bottom or sub-bottom courses through the Contractor's hauling over it or working on when the subgrade is in a wet condition, the Contractor shall at his own expense remove such mixture of subgrade material and broken stone, broken slag or gravel and replace it with clean broken stone, broken slag or gravel of the proper size, and shall roll or otherwise compact the material so as to produce a uniform, firm and even bottom course.

If the above condition occurs through no fault of the Contractor, the Contractor shall be paid both for excavating and replacing under the items "Excavation" and "Bottom Course" respectively.

Piles of filler. 44.8. All filler for top and bottom courses shall be delivered and piled alongside the road before the course in which it is to be used is placed.

Measurement and payment. 44.9. The quantity to be paid for under these items respectively shall be the number of cubic yards of compacted material in place in the completed course. The amount to be estimated shall be computed by multiplying the finished cross-section of bottom course as shown upon the plans or ordered by the Engineer, by the length of the bottom course measured along the axis of the pavement.

The price bid for the respective items shall cover the furnishing, placing, filling, rolling of the material and all labor and incidental expenses necessary to complete the work.

[1] No. 4 size is 2¾ to 3¾ in.
No. 3 size is 1¼ to 2¾ in.
No. 2 size is ⅝ to 1¼ in.

Where imported stone is specified or the local stone is suitable for both top and bottom courses, the size used for bottom course ranges from 2¾ to 3¾ in. in its greatest dimension; the smaller sized crusher output is used for the top course, for concrete and for filler; where the local material is only fit for bottom, the course is made up of stone ranging from 1 to 3¾ in. in order to use up the total output of the crusher. The stone smaller than 1 in. is used for filler, on the shoulders, and sometimes for the cheaper grades of concrete. In specifying the sized stone for a particular job, economy is considered. Stone sized from 1 to 3¾ in. is perfectly satisfactory. The only reason for limiting the usual size from 2¾ to 3¾ in. is that it leaves the 1- to 2¾-in. stone for the top course; a uniform grade is important for the top and the size mentioned gives a smooth finish.

The ratio of loose depth to rolled depth is approximately 1.3.

Where filler is not used in the construction of the bottom course more binder is required for the top; it is probable that the use of filler is the better construction but it must be of good quality.

The clause concerning teaming in the quoted specifications is a dead letter; teaming helps to consolidate the bottom provided it is distributed over the full width and care is taken in watching the course to prevent loss of shape when the traffic is first turned on or after a long-continued rainfall.

2. Screened Gravel Bottom Course.—Screened gravel 1 to 3½ in. in size is used in place of crushed stone; the course is constructed in the same manner as described above, except that a filler containing some clay or clay loam is preferable to a clean sand, and it is often necessary to wet the course in order to consolidate it satisfactorily. It is also advisable to apply a small part of the filler before the course is rolled.

A gravel bottom should be made somewhat thicker than a crushed stone bottom as the fragments do not interlock as firmly as crushed stone.

The choice between a screened gravel or crushed stone bottom depends entirely on the relative cost. Under favorable conditions a screened gravel bottom course will cost from $2 to $3 per cubic yard, rolled in place. A coarse pit run gravel is preferable to a screened gravel bottom. A typical specification follows for both gravel bottom and surface courses.

EIGHT-INCH GRAVEL PAVEMENT (STATE OF CONNECTICUT)

217. Description.—This surface shall consist of two courses, the first or bottom course to be four (4) inches in depth after rolling, and the second to be four (4) inches in depth after rolling, constructed on the prepared base in accordance with these specifications. All gravel must be screened.

218. Gravel Stone.—Gravel for the first course shall consist of good, clean, hard, durable stone, of high resistance to abrasion, uniform in quality and graded in size as follows. All gravel used must pass through revolving or fixed screens limiting the sizes so that the stone passing these screens shall be not less than one-quarter (¼) inch nor greater than

three (3) inches in diameter. It is the intent of these specifications that the gravel used shall be graded in size and that the resultant passing the screens shall show a mixture including both the maximum and minimum sized stone as specified above.

Gravel for the second course shall be of the same quality as above specified and after screening the size shall be not less than one-quarter (¼) inch nor more than two (2) inches in diameter. The gravel for this course shall also be graded in size and contain both the maximum and minimum sized stone specified.

A finishing course of gravel satisfactory to the Engineer, the size of which shall not be greater than one-half (½) inch in diameter after screening shall be finally spread over the whole surface.

219. Spreading Gravel Stone.—The prepared base shall be cleaned of all foreign matter and the gravel shall be spread upon it with shovels from piles along the side of the road or from dumping boards. It may be spread directly from approved vehicles constructed especially for this purpose, but in no case shall the gravel be dumped directly on the subgrade unless with patent spreading wagons.

220. Rolling and Filling Gravel Stone.—After the gravel has been leveled to the proper depth by hand for the first course, it shall be rolled with a three (3) wheel power roller weighing not less than ten (10) tons. All interstices shall be filled with the sand screened out of the gravel specified in paragraph 218 mixed with gravel of the size specified for the finishing course which shall be cast upon the road longitudinally and not crosswise until all the voids are filled.

For the second course the same treatment shall be followed in every respect except that enough clay shall be added to the binder when necessary to make a percentage of 12 to 15, but not to exceed 15 per cent of the binding material. The binder shall be added as directed by the Engineer and thoroughly swept into the interstices until all the voids are filled. After sprinkling the surface shall be thoroughly rolled. The addition of binder where necessary, and the sweeping, sprinkling and rolling shall continue until the course is compacted.

221. Finishing.—After the two courses have been rolled to the proper compactness the finishing course shall be applied. This course shall be one-half (½) inch in depth after rolling and shall be spread evenly over the entire traveled path area and wetted down thoroughly after which it shall be rolled until the whole mass is firm and unyielding.

222. Sprinkling Wagon.—The contractor shall provide and use continually during the construction of the road and until its final acceptance by the State Highway Commissioner or his authorized agent, one vertical spray sprinkling wagon for each 2,600 lin. ft., or fractional part thereof, of said road.

223. Basis of Payment.—This work will be paid for at the contract unit price per square yard for "8-in. Gravel Surface" in place complete, which price will include all materials, equipment, tools, labor and work incidental thereto.

3. Field Stone Subbase.—Field stone subbase is constructed, as shown in the cut, of field boulders roughly placed and filled with gravel, waste ¾-in. stone or stone chips; no attempt is made to finish the top of

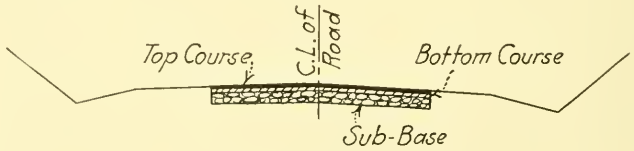


FIG. 65.—Boulder subbase.

the course exactly to line and grade, as any small inequalities can be filled with bottom stone. The depth varies from 5 to 20 in. depending on the soil encountered and the size of the available field stone but for depths of over 8 in. the foundation must be constructed as a series of

layers not exceeding 8 in. each in order to get proper compaction and filling. In designing a bottom course of this kind, care must be taken to have accurate data as to the average size of stone available. If the demands of a foundation were fully satisfied by a 5-in. subbase course, it might still be more economical to use a 7-in. course if the stone averaged 7 in., because the extra work of sorting and sledging to a 5-in. size would result in a higher cost per square yard than for a 7-in. depth.

The amount of stone and filler required per cubic yard in place is approximately as follows:

Loose depth, inches	Rolled depth, inches
6	6
10	8
15	12

This type of base requires approximately ⅓ cu. yd. of gravel or ¾-in. stone for filler per cubic yard finished subbase course.

Under favorable conditions this subbase can be constructed for $1.80 to $3 per cubic yard (1922 cost conditions).

Pit Gravel or Creek Gravel Subbase.—Stony gravel is a satisfactory material for subbase; it can be readily constructed for any depth from 2 to 24 in. as required, and where a pit or creek bar is near, the cost of such a course should run from $1.50 to $2.50 per cubic yard.

The ratio of loose to consolidated gravel for such a course is approximately 1.2.

5. Field Stone Subbase Bottom Course.—Subbase bottom course is essentially the same construction as subbase, except that, as the top

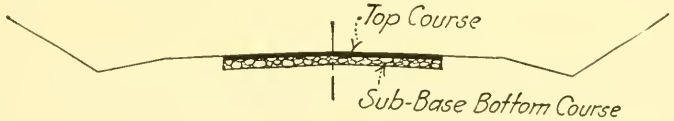


FIG. 66.—Boulder subbase bottom course.

course is placed directly upon it, the stone must be more carefully assorted as to size, more carefully placed as to line and grade, and a better grade of filler must be used.

Crushed stone (crusher run) or coarse gravel make a satisfactory filler.

The course can be of any depth from 5 in. up, depending, as for subbase, on the soil and average size of stone; it is practically impossible

to make a large stone bottom of this kind conform exactly to line and grade; a variation of 1 in. either above or below grade is usually allowed and the inequalities taken out with the top stone; this requires that the top course must be at least 3 in. to 4 in. deep after rolling.

Subbase bottom is especially applicable for long stretches of road, requiring a depth of 9 to 20 in.; depths of over 9 in. must be constructed in successive layers. It usually costs from $2 to $4 per cubic yard in place where fence stone is available, and by its use the item of higher priced bottom stone is reduced. However, on a hard foundation soils it is generally better to use 4 to 5 in. of ordinary broken stone bottom course instead of the subbase bottom course even if more expensive, because the small stone construction is more uniform in its resistance to heavy loads and the top course will wear more evenly and longer.

An extract from the 1920 New York State Specifications is given below:

SUBBASE BOTTOM COURSE

When field or quarry stone is used for constructing the foundation course it shall be of a hard, sound and durable quality, acceptable to the engineer; the stone shall be placed by hand so as to bring them in as close contact as possible. All stone must be rehandled in placing. Dumping from wagons and leveling off the piles will not be permitted. When quarry stones are used they shall be placed on edge. The depth of single stone shall in no case be greater than the depth specified for the course, the width shall not be greater than the depth, nor more than 9 in., and the length shall not be greater than one and one-half times the depth, nor more than 12 in. The distribution of the stone shall be of a uniformity satisfactory to the engineer. The long dimension shall always be placed crosswise the road. After laying, this course shall be thoroughly rolled with an approved roller weighing not less than 10 tons, and shall then be filled with stone or coarse gravel as directed and again rolled until the stones are bound together and thoroughly compacted; but no gravel shall be used for filling except under written permission of the engineer. All holes or depressions found in rolling shall be filled with material of the same quality and the surface shall be rerolled until it conforms to the lines and grades shown on the plans. When field stone is used approved tailings may be used for filling. In all cases a sufficient amount of fine material shall be used to fill all voids. In limited areas where the use of a roller is impracticable heavy tampers may be used to consolidate the material.

6. Pit Gravel Bottom or Subbase Bottom.—A stony gravel containing not over 15 per cent of loam makes a satisfactory course; the depths vary from 4 to 18 in.; pit or creek gravel even when unusually coarse has from 40 to 60 per cent of fine material; a suitable gravel for pit run bottom should not contain more fine material passing a ¼-in. screen than coarse material retained on a ¼-in. screen. If there is a large excess of fine the gravel should be screened and remixed at the bin in proper proportions.

The great difficulty in this construction is to get proper consolidation without too much delay. It is advisable to lay a course of this kind at least two weeks ahead of the top stone in order to give traffic and rains a chance to help consolidate the course. The addition of 10 per cent of

loam to clean gravel will quicken the consolidation. This can be done either at the pit by leaving a thin layer of loam when stripping which runs down with the gravel in loading or by placing from ½ to 1 in. of loam on top of the gravel as spread on the road. The author has succeeded in getting rapid consolidation by snatching loaded teams over the loose course with the road roller; the roller continually smooths out the gravel and eases the haul for the teams; the horses' hoofs and wagon wheels punch into the gravel and pack it down rapidly. Sprinkling helps. A gravel bottom consolidates unevenly and it is always necessary to reshape it somewhat after consolidation; about $0.05 per cubic yard should be allowed for this reshaping of crown and elimination of humps and hollows. A properly consolidated gravel bottom will permit a 4-ton load on 3½-in. tires passing over it without making a wheel mark over ⅛ in. deep; this is a simple available construction test. We have gone into some detail

FIG. 67.—Excellent type of construction for local farm road. Boulder base filled with gravel and surfaced with macadam.

covering this construction as it is the most economical type of bottom in a large number of cases but is not generally favored because it is harder to consolidate than the other types of bottom. With a 3-in. or preferably a 4-in. macadam top it has proved perfectly satisfactory on Class III and IV traffic roads.

The cost of a gravel bottom ranges from $1.20 to $2.20 per cubic yard in place provided the hauls are short.

The depths of gravel is gaged by blocks or lines and the ratio of loose to rolled depth is approximately 1.20.

7. Telford Base.—Telford base is rapidly going out of use in the United States because of the difficulty of maintaining a top course laid upon it. It seems to be too rigid and is more expensive than subbase

or subbase bottom course, costing about $3 to $5 per cubic yard under favorable conditions.

A good description of a telford construction is given by William Pierson Judson in "Roads and Pavements." The following quotation is an extract from his book:

On this subgrade are then placed by hand the stones forming the telford foundation, which may vary in size as shown below; each stone must be set vertically upon its broadest edge, lengthwise across the road and forming courses and breaking joints with the next course, so as to form a close and firm pavement. The stones are then bound by inserting and driving stones of proper size and shape to wedge the stones in their proper position. All projecting points are then broken with a sledge or hammer so that no projections shall be within 4 in. of the finished grade line.

The telford foundation is then rolled with a steam roller of ten or more tons weight, until all stones are firmly bedded and none move under the roller. All depressions are then filled with stone chips not larger than 2½ in., and the whole left true and even and 4 in. below the line of finished grade and cross-section.

A good workman will average about 20 min. in setting a square yard of this telford foundation, which may be formed of any kind or quarried rock which is most available.

The practice in 1901 in the states named is here shown.

Sizes of Stone for Telford Foundation, in Inches

State	Depth as set on edge		Width as set		Length set across road		Remarks
	Maximum	Minimum	Maximum	Minimum	Maximum	Minimum	
New Jersey	8	8	4	..	10	..	Alternate end stones, double length.
Mass.	6	5	10	4	15	6	2-in. gravel rolled on subgrade as base.
Connecticut	8	8	10	6	18	8	Macadam covering formed in one layer.
New York	8	6	10	4	15	6	Used only on unstable ground as foundation for macadam.

TELFORD COURSE—SPECIFICATIONS (STATE OF CONNECTICUT)

95. Description.—This base course shall consist of a foundation for the surface course or pavement, eight (8) inches in depth unless otherwise specified, constructed on the prepared subgrade, of large stones wedged in place by the addition of smaller ones, in accordance with these specifications.

96. Materials.—The materials for this work shall consist of approved, sound, tough, durable stones, free from clay, loam or other foreign substances. The pieces shall be approximately rectangular in section having a depth of eight (8) inches after napping, a width of from six (6) to ten (10) inches and a length of from eight (8) to eighteen (18) inches. The small stone for filling the voids in the large material shall consist of material at least equal in quality to that of the large stone.

97. Construction Methods.—The telford stone shall be laid in courses, by hand, with the broad edge down and with the long dimension at right angles to the center line of the roadway. They shall be laid perpendicular to the finished surface in close contact, breaking joints, and shall be wedged in their correct position by inserting and driving, in all places where practicable, small stone of suitable size. All projecting points shall be napped off and the remaining voids filled with small stones, so that the finished surface shall be true and uniform. This base course shall be rolled with a three (3) wheel power roller, weighing not less than ten (10) tons, until compacted satisfactorily and true to the grades and cross-sections given. The filling and rolling shall follow the laying of the large stone closely. This course shall not be constructed more than one thousand (1,000) linear feet in advance of the surface course or pavement, unless otherwise permitted by the Engineer.

If, at any time, the subgrade material should become churned up or mixed with the telford stone, the Contractor shall, without additional compensation, remove the mixture, reshape and compact the subgrade and replace the materials removed with clean telford stone, which shall be rolled and filled until compacted satisfactorily and uniform with the surrounding surface.

98. Basis of Payment.—This work shall be paid for at the contract unit price per square yard for "8-in. Telford Base Course" complete in place ,which price will include all materials, equipment, tools, labor and work incidental thereto.

Distribution of Stone in Foundations.—On light travelled single track roads most of the traffic normally keeps to the middle 10 to 12 ft. It would therefore appear logical to make the central portion of the road thicker than the sides. This applies without doubt to roads of moderate

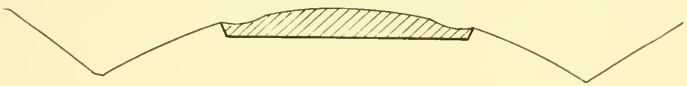


FIG. 68.—Shallow ruts along edge of Class I traffic macadam road.

traffic where the vehicles generally travel in the center of the macadam and only occasionally turn out to pass but, for heavy traffic double track roads the idea is wrong (see also page 75). On such roads the greatest wear and heaviest wheel load occur about 1 ft. from the edge of the hard pavement and many of these roads develop the shape shown in

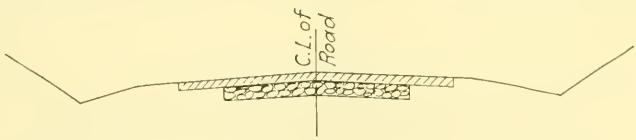


FIG. 69.—Mushroom type of foundation Class IV traffic roads.

Fig. 68. It therefore seems advisable to keep the full depth of metalling for the full width on Class I, II and III traffic roads.

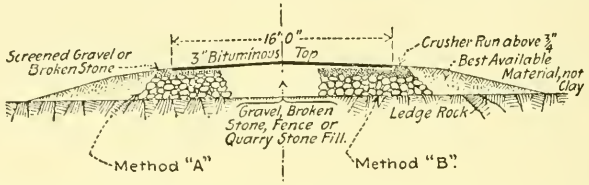
For Class IV traffic the varying thickness indicated in Fig. 69 is applicable.

Special Foundation Problems.—Long stretches of comparatively level ledge rock, muck and vegetable loam may be placed under this head.

Where a road is on the surface of ledge rock for any distance, the usual cross-section of part cut and part fill cannot be used because of the

high cost of shallow rock excavation for ditches; the grade should be lifted to make the normal section fill and the best available material (not clay) used in its construction. Where conditions of this kind prevail, dirt is usually hard to obtain and often a stone fill is cheaper and also more satisfactory.

The construction shown (Fig. 70) was used for a stretch of 2½ miles on the Leroy-Caledonia State Highway in New York, where ledge rock was encountered as described.



Fill can be made of fence stone, gravel, quarry spalls, stone chips, or run of crusher stone over ¾ in. in size.

Method A.—Boulders up to 2 cu. ft. can be used, placing the largest in the bottom of the fill: the top layer must be fairly uniform and not over 8 in. in size and must be roughly placed by hand to reduce the voids as much as possible, provided this layer of large stone is within 4 in. of the bottom of the top course. The top 8 in. to be filled with stone chips or gravel and a cushion of at least 2 in. of screened gravel, stone chips or crushed run of broken stone over ¾ in. size to be placed on top to bring the fill to the correct grade and crown for the top course.

Method B.—Same material and manipulation as Method A, expect that provided the top of the boulder fill is more than 4 in. from the bottom of the top course the top layer of the boulder fill need not be placed by hand (see sketch, Method B).

Fig. 70.—Special foundation where road is subjected to flood water ponding in spring of year.

The price for the stone fill was $1.23 (1910) per cubic yard in place constructed as shown; the road was built in 1910 and has given satisfaction; the minimum thickness of top for such a fill is 3 to 4 in. as it is impossible to construct it exactly to line and grade; it was found that by allowing a variation of 1 in. either above or below the grade elevation, the

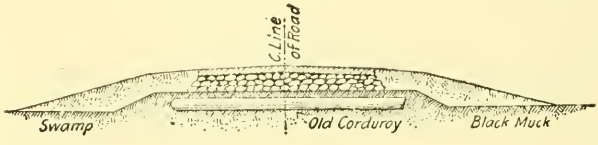


Fig. 71.—Special foundation over old corduroy road through swamp.

fill could be readily constructed, and these small inequalities were taken out with the top stone. A top course having such a variable thickness should be paid for by weight and not by volume in place.

Peat, Muck, Vegetable Loam or Silt.—Where the material is semi-fluid, the only solution is a pile and grillage foundation.

Swamps, as ordinarily encountered, can be treated successfully by using a corduroy or mattress foundation covered with a deep fill of

gravel or large stone. In some cases where the muck is comparatively stiff, a gravel or boulder fill alone will give a satisfactory foundation.

Where swamps are crossed by improved roads, the location usually follows the old road which has often been corduroyed in the past; in such cases the old foundation should not be disturbed; a sufficient additional depth of stone can be added to keep the shape of the section intact.

As an example, the Scottsville-Mumford New York State improvement crossed a 1,000-ft. stretch of muck on the old road location; it was found that the original cedar corduroy was in good shape; an 18-in. depth of large boulders was placed on the old foundation and surfaced with 6 in. of broken stone macadam. This stretch of road has kept its shape and has not settled, it affords a good example of the fact that in many special cases the depth of the stone is determined by trial; the boulders were put on in successive layers of 6 in. each until there was no material movement under the roller and then surfaced with the broken stone macadam. Under a heavy load the whole roadbed will vibrate for 100 ft., but the shape remains intact (see Fig. 71).

Economical Foundation Design Macadam Roads.—The economical design of foundation courses may be summarized as follows:

For moderate traffic use pit run coarse gravel if available varying the depth to suit the soil. If gravel is not available use a macadam bottom for ordinary soils and field stone subbase or subbase bottom for bad foundations. The economy in the design of macadam roads is greatly increased by utilizing local material, preferably uncrushed, to its fullest extent. If the supply of local material is limited it should be used for as much as the road as possible and advantage should be taken of the different local supplies by changing the design to allow their use with short hauls.

Uniform designs which disregard limited amounts of local materials often raise the cost from $1,000 to $2,000 per mile.

Conclusions.—In the design of a road, the amount of material required for the foundation courses can only be approximated. This is the only item in the preliminary estimate that cannot be figured within definite limits. It can be closely estimated if careful data on the soils is obtained from local people and from the preliminary survey but some leeway must be given the constructing engineer so that he may vary the estimated depths to meet the construction conditions and build a consistent road. It will be noted that the depths recommended in Chap. II are greater than those shown in most of the state sections throughout the book. This increase in depth is based on the observed action of traffic on the older macadam roads, which unless recapped with from 3 to 6 in. of additional stone are failing under heavy modern traffic. A macadam foundation is more suitable in northern climates for nine-tenths of the roads than a rigid pavement because it is flexible under frost action and

with sufficient depth will hold the heaviest loads, but practice in macadam design and maintenance has heretofore lagged behind the traffic requirements in the matter of depth while rigid pavement strength is well abreast of the times. The author has been amused at the recent comparisons of the effect of Army truck traffic across New York State on rigid and macadam roads. A considerable mileage of old thin macadam roads failed in spots but where a reasonable depth of macadam prevailed no foundation failures occurred. A blare of trumpets hailed the failure of the old cheap inadequately maintained macadams and great stress was laid on the fact that the rigid types held. This is mentioned to illustrate a phase of the present campaign for rigid types which the author considers unwarranted and dangerous from the standpoint of reasonable road design as it tends to discredit macadam construction. While we do not advocate macadam on Class I roads its use on Classes II, III and IV should be encouraged. (For traffic classification, see page 38.)

Macadam foundation failures are due to insufficient depth, insufficient consolidation during construction and poor grade filler. The matter of filler is very important; coarse sand, pea gravel; or stone screenings are preferable for crushed stone bottom courses and *earth or loam that softens when wet should never be allowed.* Filler should be a separate item separately paid for. The filler for boulder or telford base should be hard coarse gravel, ⅜-in. crushed stone or stone chips.

Macadam foundation failures are due to the same cause as concrete failures or brick failures or any other failure—*ignorance and carelessness.*

MACADAM SURFACE COURSES

Waterbound Macadam Pavements.—Waterbound macadam surface courses are constructed of crushed fragments of suitable rock filled with rock dust and sprinkled and rolled until firm and hard. All types of gravel, boulder and stone bases are used as described in the first part of this chapter. Standard Specifications are given on page 212.

Waterbound macadam pavements are satisfactory and economical under light traffic up to about 800 vehicles daily provided they are systematically maintained and surface ravelling prevented by means of applications of calcium chloride or light bituminous surface treatments. They have been used successfully under quite heavy traffic, 2,000 to 3,000 daily, but for a volume of over 500 to 800 daily the maintenance difficulties generally result in the selection of a bituminous macadam

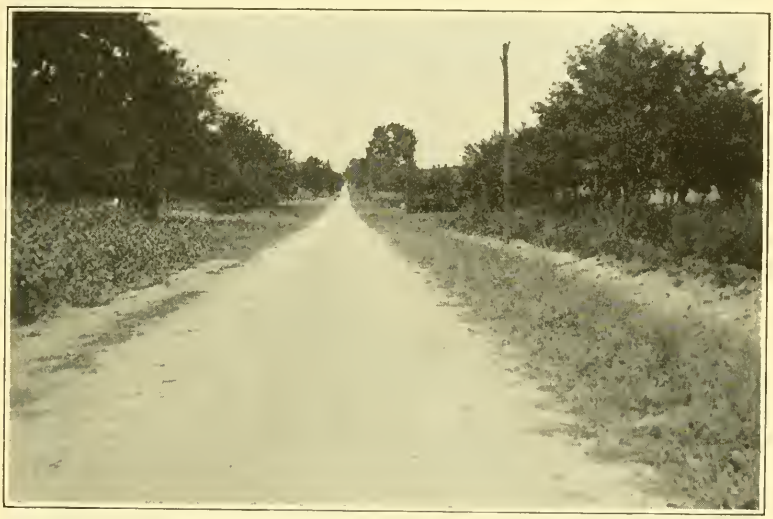


FIG. 72.—Ten-ft. width local stone macadam serving agricultural Class IV very satisfactorily. Note shallow ditch which adds to safety of traffic. Crushed stone obtained by crushing mixed fence stone boulders, granite gneiss and hard sandstone. Simple maintenance consisting of rolling in the spring with repair of holes, addition of some screenings and calcium chloride or light oiling.

penetration type. The essential advantage of the waterbound type lies in low first cost, simplicity of construction, ease of repair and safe and easy riding qualities if well constructed and maintained. Under normal agricultural district traffic of less than 500 vehicles daily, the final cost of this type of pavement including yearly maintenance and renewal is distinctly lower than higher types of surface. When well designed and

constructed of adequate thickness (see pages 94 to 102) they can be used effectively as a base for higher type surfaces. Waterbound

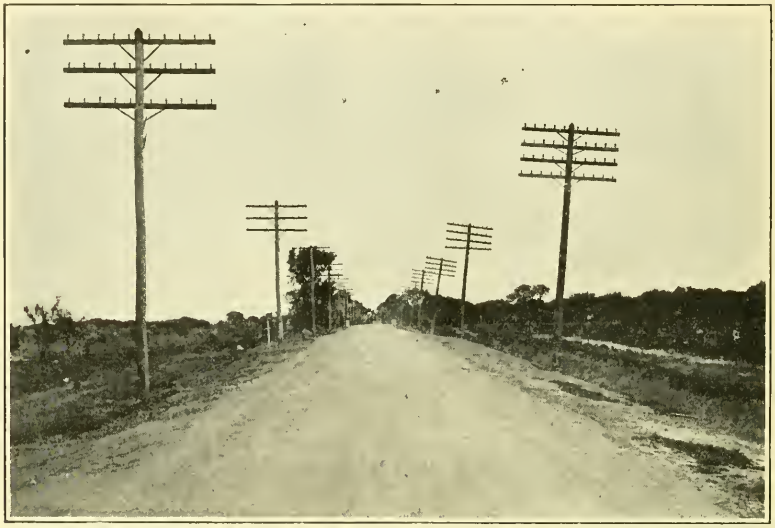


FIG. 73.—Limestone waterbound macadam serving Class II traffic on primary state system. This road served very well for about 10 years when it was recapped with Topeka mix to reduce maintenance cost. Maintenance consisted of repair of holes with cold patch and systematic light oiling.

FIG. 74.—Crushed acid slag macadam used as temporary improvement in outskirts of city to promote real estate development. Will eventually be resurfaced with some higher type of surface utilizing macadam for base course. Serves this purpose very well.

macadam is a very satisfactory type for local town or county roads and for Class III traffic on primary state systems.

Waterbound macadams including base and top range in initial construction cost from \$1.50 to \$3 (\$1.90 average) per square yard depending on character of foundation soil, traffic and local material supply; the

FIG. 75.—Applying granulated calcium chloride by means of agricultural drill. About $1\frac{1}{4}$ lb. per square yard is applied for the first application and about 1 lb. per square yard for succeeding applications. Two to three applications per season should keep a new waterbound road in shape under Class III traffic. The particular value of calcium chloride is to prevent ravelling the first season. Oiling is generally resorted to the second season after the road has been well compacted by traffic.

maintenance charge will range from \$0.03 to \$0.10 per square yard depending on varying conditions and the renewal charge distributed over

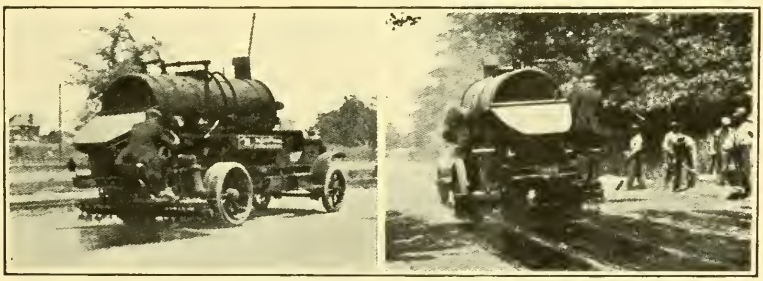


FIG. 76.—Usual method of applying light oil treatment. Half of the road is generally oiled, covered and allowed to stand until the sticky condition disappears; the other half is then oiled. This prevents a disagreeable condition of the entire surface for traffic. The amount of oil used varies from 0.2 to 0.3 gal. and the amount of sand cover from 20 to 30 cu. yd. per mile of 16-ft. road although it may run as high as 50 where unusual conditions prevail.

the life of the surface will probably average about \$0.05, Class IV Traffic, to \$0.11 Class II Traffic per square yard per year, 1922 cost conditions.

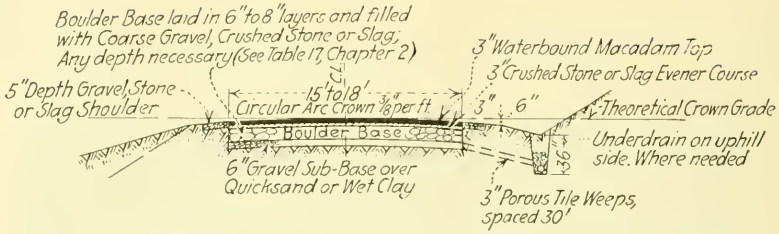


FIG. 77.—Recommended waterbound macadam pavement section boulder base construction Class II traffic.

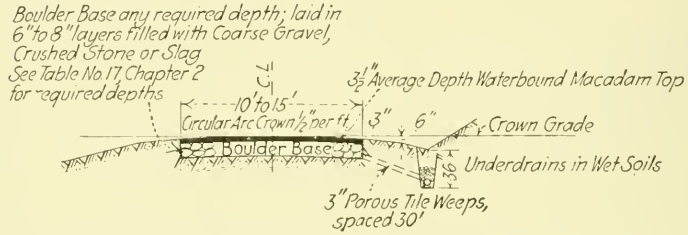


FIG. 77A.—Recommended waterbound macadam pavement section boulder base construction Class III or IV traffic.

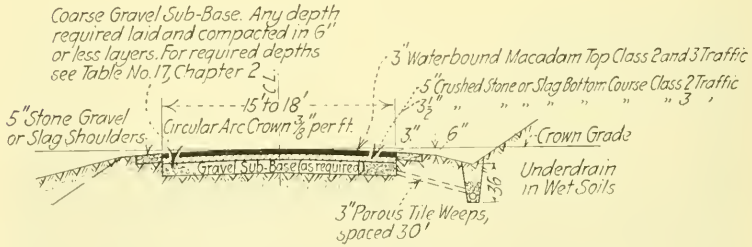


FIG. 78.—Recommended waterbound macadam pavement section gravel foundation Class II or III traffic.

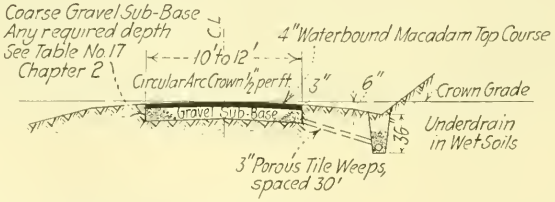


FIG. 78A.—Recommended waterbound macadam pavement section gravel foundation Class IV traffic.

A surface life of 6 to 12 years is reasonable for this type under a traffic of 300 to 800 daily (10-hour count) if the road is fairly well maintained although there are a considerable number of cases which do not fall within these limits (see Chap. IV).

The use of fairly good materials is desirable but the high standards required for heavy traffic roads should not be applied to this type as needless cost is to be avoided under light traffic conditions. Materials, Details of Design and Inspection Details are discussed later.

The following recommended designs can be used with assurance of reasonably good results:

Recommended Designs.—The accompanying recommended designs represent conservative practice: a large mileage of thinner pavements have been built and have served for a short time with moderate satisfaction: as a matter of fact no well constructed macadam road having a depth of at least 80 per cent of the values recommended can be a serious failure as it can be easily strengthened in the future by the addition of stone depth. It however seems undesirable in most cases to resort to resurfacing in too short a period and for this reason caution should be exercised in reducing the depths shown in districts permitting a legal gross vehicle load of 28,000 lb. (See Figs. 77 and 78, page 206.)

SUITABLE MATERIALS

Surface Course Coarse Aggregate.—Any tough, hard crushed stone which breaks in roughly cubical form and does not air or water slack is suitable for coarse aggregate. Limestone, granite, gneiss, trap and hard sandstones are generally satisfactory. For Class III traffic (300 to 800 daily) it is desirable to use a stone having a French coefficient of hardness of 7 or better (6 per cent of wear or less) see Appendix A for tests. Stone as soft as 4 French coefficient has been used with moderate success but where a soft stone is necessary on account of prohibitive cost of a better grade, the size should be increased. The usual size of coarse aggregate for top course is 1¼ to 2½ in.; for soft stone the size should be 2½ to 3½ in. using the smaller grades for the foundation course. For purely local roads carrying less than 300 vehicles daily, practically any available local stone which does not air or water slack can be used. Crushed slag is suitable under light traffic. Crushed slag is not advocated for top course on the heavier traffic roads. Crushed slag should weigh at least 1,800 lb. per cubic yard loose measure and show a per cent of wear not exceeding 12 by the standard slag abrasion test.

Surface Course Binder.—Limestone screenings make the best filler as they have considerable cementing quality and bond the stone well. Where the coarse aggregate is trap, granite or sandstone, it is difficult to get a good puddle and on the more important roads at least 50 per cent of

limestone dust is mixed with the other screenings. Surface oiling tends to minimize the necessity for limestone screenings but the author prefers at least 50 per cent limestone dust on waterbound macadam roads on primary state systems. For purely local agricultural roads, the natural rock screenings are used.

Oiling.—There are a number of satisfactory light asphaltic oils and refined tars on the market which serve well for surface applications. The quality of these bituminous materials is discussed under "Maintenance," Chap. IV. Specifications are given in Chap. IV. Personally, the author prefers a good cold tar product to asphaltic oils for surface application as they seem to have better penetration and to harden quicker. They are probably a little more slippery and perhaps not quite as durable but on the whole, I believe tar to be superior to asphalt for surface treatment of waterbound macadam roads. For surface oiling of penetration bituminous macadam, it is probably best to use asphaltic oil where the pavement binder is asphalt and to use the cold light tar where the pavement binder is a heavy tar.

Macadam Bottom Courses, Coarse Aggregate.—For crushed stone bottom courses, any stone which will stand the necessary rolling to compact and which does not water slack is suitable. Crushed slag weighing not less than 1,800 lb. per cubic yard loose makes an excellent material. No maximum per cent of wear is recommended. The cheapest available source is generally used but it is necessary to decide what source will be used and set the maximum per cent of wear for any specific contract to prevent argument and the use of needlessly inferior material. The size usually specified is $2\frac{1}{2}$ to $3\frac{1}{2}$ in. but this is merely to permit the use of the $1\frac{1}{4}$- to $2\frac{1}{2}$-in. size for top and a perfectly satisfactory bottom can be constructed of well mixed stone ranging in size from $\frac{3}{4}$ to $3\frac{1}{2}$ in. provided pockets of fine and coarse stone are not permitted. Tailings can be used if knapped to the proper size.

Macadam Bottom Filler.—Coarse sand, stone or slag screenings make the best filler; sandy loam is satisfactory on light traffic roads. Filler is very important; it should be a separate item separately paid for and no material which softens when wet should be used even for unimportant roads. *A considerable number of macadam failures are directly traceable to soft filler.*

Boulder Base Coarse Aggregate.—Any ordinary boulder or quarry stone is suitable provided it is not rotten. Large boulders must be sledged to suitable size. Maximum size is usually placed at 8 in. for any dimension with the depth thickness not greater than the finished depth of the course (see specifications, page 196).

Boulder Base Filler.—Crushed stone or slag or coarse hard gravel containing not over 15 per cent of loam are satisfactory. Fine sand or loam should never be used.

Gravel Bottom and Subbase.—A coarse hard gravel containing not over 15 per cent of loam and having a grading in size of at least 50 per cent retained on a ¼-in. mesh screen makes an excellent base. If the pit run is non-uniform and excessively fine, it should be screened and remixed in the proper proportions of fine and coarse.

Amounts of Material Required per Cubic Yard of Consolidated Macadam.—*Top Course* requires approximately 1.3 cu. yd. loose measure crushed stone (1¼- to 2½-in. size) and approximately 0.5 cu. yd. stone screenings for binder and wearing course. The weight of this material will vary according to the kind of stone used. Commercial plants will furnish data of loose measure weights of their standard sizes. The following table gives a fairly close means of estimating weight.

WEIGHTS OF MATERIALS[1]

Kind	Specific gravity	Broken stone, pounds per cubic yard	
		Loose spread 45 per cent voids	Compacted 30 per cent voids
Trap	2.8	2,590	3,300
	2.9	2,680	3,420
	3.0	2,770	3,540
	3.1	2,870	3,650
Granite	2.6	2,400	3,060
	2.7	2,500	3,180
	2.8	2,590	3,300
Limestone	2.6	2,400	3,060
	2.7	2,500	3,180
	2.8	2,590	3,300
Sandstone	2.4	2,220	2,830
	2.5	2,310	2,940
	2.6	2,400	3,060
	2.7	2,500	3,180

[1] Asphalt Association Pocket Reference.

In Western New York for limestone having a specific gravity of approximately 2.7 (170 lb. per cubic foot), the total weight of stone and screenings per cubic yard of finished waterbound macadam top course including the wearing course is close to 4,400 lb. Fifty to eighty gallons of water are required to puddle a cubic yard of top course.

Macadam bottom course requires approximately 1.3 cu. yd. loose measure of crushed stone, slag or screened gravel ranging in size from 2½ to 3½ in. and approximately 0.35 cu. yd. of sand or stone screening filler. Where the bottom is constructed of mixed sizes from 1¼ to 3½ in., it requires approximately 1.25 cu. yd. loose per consolidated yard of finished macadam.

Pit run gravel subbase requires approximately 1.2 cu. yd. loose measure per consolidated cubic yard.

Field stone boulder subbase requires 1 cu. yd. of boulders per cubic yard of finished course where only one layer of uniform sized boulders is used. Such a base requires 0.5 cu. yd. of gravel or crushed stone filler. Where the depth of the base is greater than the average size boulder, approximately 1.25 cu. yd. of boulders are required per cubic yard of finished base with from 0.3 to 0.4 cu. yd. of gravel or crushed stone filler.

Design.—The design of macadam pavements considers the proper use of local materials, the depth required on different soils, width, crown, etc. Chap. II developed the detail theory of total macadam depth under different traffic and soil conditions. Table 17, page 100, gives this depth data. Having established the total depths, alternate estimates are made on the basis of utilizing gravel, boulder or crushed stone base courses. The variations in depth of the macadam surface on these different bases were developed in Chap. II, page 99. The most economical combination is adopted (for example, see Official Report, page 156). Where boulder and gravel are both available, it is generally better and more economical to use boulder base, gravel filled, with a thinner macadam surface than to use good gravel with a thicker macadam surface. While it is desirable to keep the depth of top course to a minimum on account of the high cost of this part of the pavement, it is not safe to use less than a 3 in. consolidated depth on account of the tendency to ravel and kick out.

Widths.—Widths were discussed in detail in the first book of the series and summarized in Chap. II, page 70. Extra widening at sharp curves is desirable for roads carrying over 300 vehicles daily, see Tables 10 to 10B, page 71. On light traffic local roads, this is a useless refinement.

Crown.—A circular arc crown is a good form. For the narrow single track local roads, a total crown of ½ to ⅝ in. per foot of half width is a good rule. For the wider roads 16 to 18 ft. and for village streets, the crown should be about ⅜ in. per foot on account of future use of the macadam as a base for asphaltic concrete or small block surfacings. One way banking on sharp curves is desirable for rural roads carrying over 300 vehicles daily but is a useless refinement on light traffic local roads.

Amount of Superelevation.—A mathematical analysis of superelevation is not very satisfactory as there are too many variable factors. Cars take easy curves at higher rates of speed than the sharper curves

which fact tends to equalize the bank crown. The pavement must not be tipped enough to make it dangerous for slow-moving vehicles. The full superelevation is carried around the entire curve from P. C. to P. T. and reduced to the normal crown at points from 100 to 200 ft. along the tangents from the P. C. or P. T. The normal grade is carried around the center line of the pavement and the outer edge raised and inner edge lowered to produce the required side tilt (see Fig. 79). It is sometimes desir-

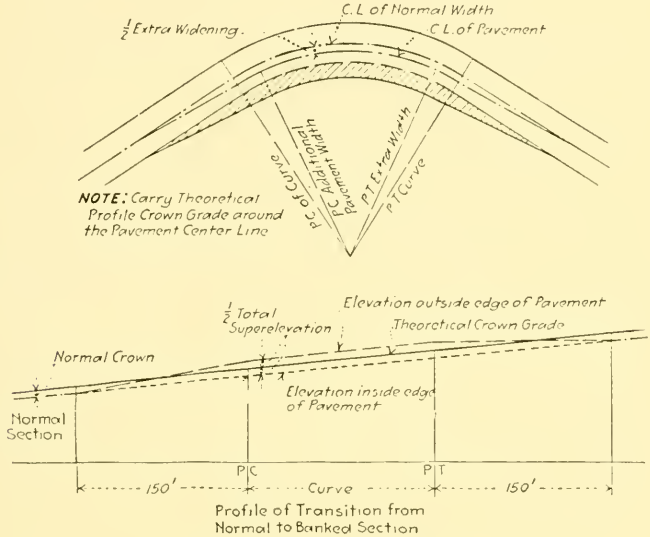


Fig. 79.—Banking curves.

able to hold the inside at normal grade and bank entirely by raising the outside. Each case looks differently in the field and the method should be left to the constructor.

Current practice favors the following one way crown slopes on curves to provide reasonable comfort and safety for vehicles driven at rational speeds.

Table of Crown Slopes on Banked Curves

Radius of road center line in feet	Recommended uniform crown slope
50– 200	1¼ in. to 1 ft.
200– 500	1 in. to 1 ft.
500– 800	¾ in. to 1 ft.
800–1,000	½ in. to 1 ft.

Note.—Curves having a radius over 1,000 ft. are not banked generally.

Specifications.—The following specification indicates the essentials of current practice in construction.

WATERBOUND MACADAM TOP COURSE AND SURFACE OILING

ITEM 48.—TOP COURSE—WATERBOUND MACADAM—BROKEN STONE

ITEM 48A.—TOP COURSE—WATERBOUND MACADAM—BROKEN SLAG

48.1. Under this item the Contractor shall furnish and place upon the bottom course, broken stone or broken slag to form the top course.

48.2.[1] The top course shall, except as noted below, consist of No. 3 broken Material. stone or broken slag as shown on the plans and of the thickness shown thereon, together with the binder necessary to properly fill and bind the course. The binder shall consist of screenings and No. 1 stone or No. 1 slag mixed.

48.3. All binder for this course shall be delivered and placed in piles alongside the road before the course is placed.

The required thickness of top course shall be composed of No. 3 stone or slag and spread evenly upon the bottom course, using cubical blocks for gaging, to such a depth as to insure the required thickness after it shall have been thoroughly rolled and compacted. Care shall be used in the spreading of the stone or slag that no irregularities in the contour shall develop in the rolling; every such irregularity that does occur the Contractor shall remove before adding the smaller material. The rolling shall be done with a 10- to 12-ton self-propelled roller of approved pattern, and shall be co ntinued until the layer of stone or slag does not creep or wave ahead of the roller.

After the stone or slag has been compacted to the satisfaction of the Engineer, a light coating of binder shall be spread on dry by shoveling from piles previously placed alongside the pavement, and immediately swept in and thoroughly rolled. Care must be taken throughout to add the binder only in light applications and to thoroughly sweep each application in order that the maximum amount of binder may be worked in to fill the voids. The spreading, sweeping and rolling shall be continued until no more binder will go in dry, after which the macadam shall be sprinkled and immediately rolled. Water shall not be used so long as it is possible to introduce more dry screenings into the surface. If the subgrade should become wet to such an extent that the pavement becomes unstable and waves under the roller it is an indication that the top course was not thoroughly filled dry and the roller shall be taken off and this portion left to dry out before puddling is resumed. Small V-shaped surface drains shall be cut through the shoulders to accelerate the drying out of macadam.

More screenings shall be added where necessary, and the sweeping, sprinkling and rolling shall continue until no more screenings can be forced into the voids. This condition will be apparent when a wave of water and excess screenings shows in front of the roller wheels. After the wave of grout has been produced over the whole section of the macadam this portion shall be left to dry out, after which it shall be opened to traffic. The macadam shall be repuddled and back-rolled on succeeding days as much as may be necessary to secure satisfactory results. The macadam shall then be covered with a wearing carpet of screenings at least three-eighths of an inch thick. After the road has been opened to traffic for ten days, or as the Engineer may direct, this wearing carpet shall be again spread by sweeping the surplus from the sides to the center of the pavement, and it shall be maintained and renewed until the whole road is accepted. During all the working hours when the roller is not used for rolling the fills, subgrade, shoulders, and unfinished courses of the pavement, it shall be employed in back-rolling the earlier portions of the macadam.

Measurement and payment.

48.4. The quantity to be paid for under this item shall be the number of cubic yards of compacted material in place in the completed course. The amount to be estimated shall be computed by multiplying the finished cross-section of the top course as shown on the plans or ordered by the Engineer, by the length of the top

[1] No. 1 size passing ⅝ in. screen; No. 3 size 1¼ to 2½ in.

course measured along the axis of the pavement, except that no payment will be made for the filling of any depressions developing during construction.

The price bid shall cover the furnishing, placing, rolling, filling and puddling of the material, and all labor, material and incidental expenses, necessary to complete the work.

No. 1 stone, slag or gravel, chips or screenings remaining loose on the surface after the work is completed or an excess of binder compacted on top of the stone shall not be estimated as a part of the depth of the top course, but payment therefore shall be included in the price bid for this item.

SURFACE TREATMENTS WITH BITUMINOUS MATERIAL

51.1. Under this item the Contractor shall apply bituminous material and shall apply broken stone or gravel of specified sizes as a wearing carpet to a new or old pavement of macadam, concrete, or any other substance or type, as shown on the plans or ordered by the Engineer.

51.2. If the pavement to be treated is a newly built macadam or concrete, after it shall have become thoroughly dried and hardened, it shall be swept clean of all dust, dirt or other loose material; if ordered by the Engineer, the sweeping of the macadam shall be continued until the voids are exposed in the surface to a satisfactory depth, not exceeding ½ in. The price bid, under this item, shall include the aforesaid cleaning of the pavements.

If the pavement to be treated is an old macadam or old concrete, the cleaning shall be paid for under item "Cleaning Old Pavement."

51.3. After the pavement shall have been cleaned to the satisfaction of the Engineer, and when dry, the bituminous material shall be uniformly sprayed over the surface by means of an approved pressure distributor. The bituminous material for hot application shall be heated to a temperature between 250 and 350°F. as required, and when tar is used, it shall be heated to a temperature between 200 and 250°F. as required.

The amount of bituminous material to be used in any one application shall not be less than one-sixth nor more than one-half gallon per square yard, the precise quantity depending upon the character of the pavement, the materials and the local conditions. The Contractor shall, therefore, be subject entirely to the direction of the Engineer in this respect.

51.4. The bituminous material applied as above specified shall then be immediately covered, while soft, with a uniform layer of approved broken stone of No. 2 or No. 1 size, after which the stone shall be rolled with a self-propelled roller of approved weight. If ordered by the Engineer another application of bituminous material shall then be made to be followed by an application of approved No. 2 stone or approved No. 1 stone, and again rolled to the satisfaction of the Engineer.

The quantity of No 2 stone and of No. 1 stone to be used shall be sufficient to completely cover the bituminous material and shall be spread in two or more thin applications, the roller being used after each spreading. The total amount of stone to be used after each application of the bituminous material being that which will become imbedded under the pressure of the roller. The final application of the stone shall be of No. 1 size.

51.5. Gravel, which has been tested and approved for use, may be substituted for broken stone if screened to produce particles corresponding with No. 2 and No. 1 sizes.

51.6. No bituminous material for surface treatment shall be placed between October 15th and May 15th, except by written permission of the Engineer, nor when the air temperature on the work is below 50° F., nor when the pavement is damp or in an otherwise unsatisfactory condition.

51.7. Under this item the Contractor shall be paid for the number of gallons of bituminous material furnished in and incorporated in the work in accordance with these specifications and the orders of the Engineer. Bituminous material, that has been wasted or that has been rendered unfit for use by over-heating or by long-continued heating, shall not be paid for. For purposes of measurement, a gallon shall be a volume of 231 cu. in. and measurement shall be based on the volume of the bituminous material at a temperature of 60°F.

The price bid shall include the furnishing, hauling, heating and applying the bituminous material, and shall also include the spreading, rolling and incorporation of the stone into the wearing carpet.

This item shall not include the furnishing of the No. 1 and No. 2 stone or gravel, nor the delivery of same along the side of the road; these will be paid for under Items Screened Gravel or Broken Stone Loose Measure, respectively.

Construction Equipment and Methods.—Construction equipment is to be discussed in detail in the fourth book of this series; to give the student an idea of usual equipment, a short list is given below.

Grading

Heavy cuts	Small steam shovel or large size Keystone grader, dump wagon delivery or narrow garage track and car delivery.
Ordinary cuts short haul	Wheel and slip scrapers hauled by teams or small tractors or traction engine. Keystone grader, dump wagon haul.
Light cuts and finishing	Plow and hand excavation. Dump wagon haul. Blade scraper and hand pick and shovel trimming.

Consolidation by teaming and 10-ton roller.

Concrete and Pipe Culverts

1 bag batch concrete mixer.

Small tools, including iron tamper, spader, edging tools and carborundum finishing brick.

Tripod with chain block hoist for handling reinforced concrete pipe 24 in. or more in diameter.

Gravel Subbase.—Ordinary grading equipment for loading gravel at pit. Truck or dump wagon delivery. Either dump and spread by hand or if trucks are used, spread with manger spreader. Consolidated by combination of teaming and steam roller or traction engine.

Boulder Base.—Generally hand loading. Generally dump wagon delivery on account of difficulty of reaching source of supply with trucks. Boulders dumped on grade, placed by hand. Filled with gravel or crushed stone previously placed on shoulder and rolled with 10-ton roller.

Macadam Courses.—Quarrying machinery (Fig. 83).

Crushing plant (Fig. 84).

Unloading plant for rock delivery in railroad cars, generally either elevator unloader, clam shell unloader, or for small jobs, hoppers with hand shovelling.

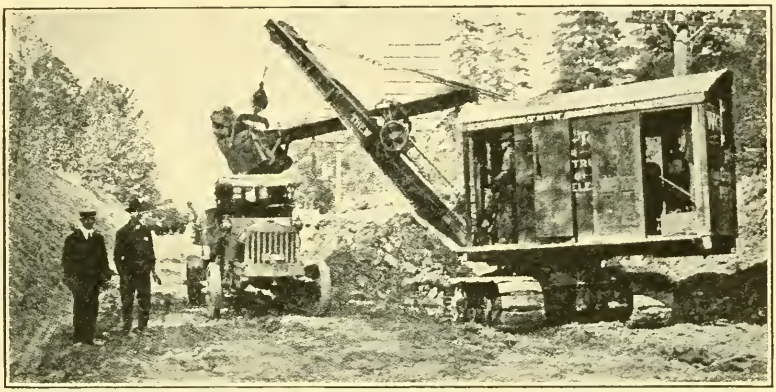


FIG. 80.—Small revolving steam shovel with caterpillar traction. Very effective for moderately heavy highway excavation.

Delivery of materials to grade by either trucks or teams; teams preferable for new construction, particularly for bottom course where

FIG. 81.—Heavy steam shovel. Rock work in western mountain highway construction.

haul does not exceed 1 mile; trucks preferable for reconstruction of old solid roads or long hauls over 1 mile.

Macadam stone spread either by hand or manger spreaders and trued up by hand. Stone rolled with 10-ton roller; filled by hand from piles

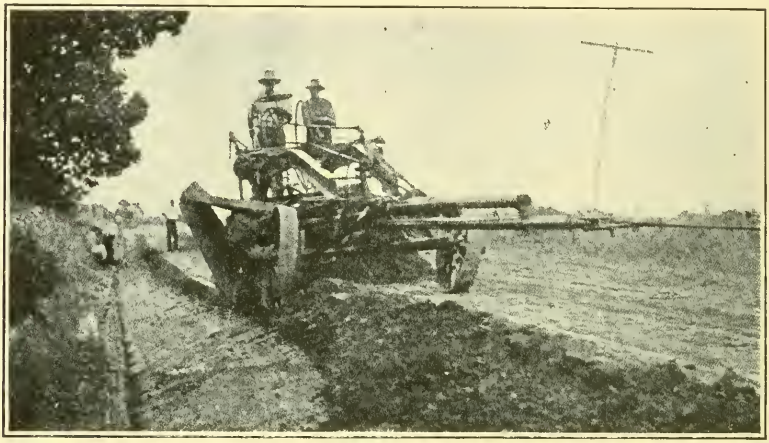


Fig. 82.—Heavy blade scraper drawn by 5-ton caterpillar tractor shaping shoulders and ditches.

previously dumped on the shoulders. Top course puddled by sprinkling macadam by means of sprinkling carts; pipe line and hose or pipe line and sprinkler attached to roller; the last method is the best and cheapest;

Fig. 83.—Typical small local quarry layout for road work.

the sprinkling pipes on the roller throw a strong stream directly on to the wheels of the roller instead of on to the stone; the water is fed to the roller

by means of an armored hose about 250 ft. long; pipe line faucets are provided at intervals of 250 to 300 ft. The road is puddled in sections of 100 to 200 ft. at a time.

FIG. 84.—Typical small portable crusher and bin for utilization of local stone supplies. Traction engine power.

Inspection Details.—The following brief statement gives the essentials of inspection.

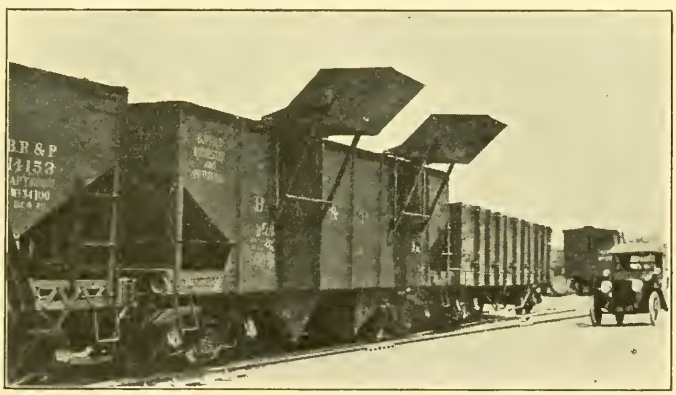


FIG. 85.—Hopper unloaders for small jobs where it would not pay to use elevator or crane. Hand shovelling into hoppers. Quick dump into trucks, saving truck time in loading.

Culverts.—Culverts are usually constructed before the road is graded. They should be completed well in advance of the macadam, because even though the back-fill is carefully tamped there is bound to be some addi-

tional settlement under traffic action, and if the macadam is laid over a fresh back-fill depressions are sure to develop which, if not repaired, make "thank-you-marms" in the road or introduce areas of no soil support under rigid slabs which often produce cracks unless the pavement is thickened enough to bridge the trench.

FIG. 86.—Roller in action. Roller must not be reversed suddenly. In stopping it should roll easily to rest and start easily.

Cast-iron Pipe.—Trenches for pipe are dug the required depth, making the bottom wide enough to allow the joints to be properly calked. This requires a trench 18 to 24 in. wider than the pipe diameter, *i.e.*, for a 12-in. pipe the trench is 30 to 36 in. Bell holes are dug as shown in Fig. 87, so that the pipe will have a uniform bearing its entire length. At no point should it rest directly on boulders or ledge rocks.

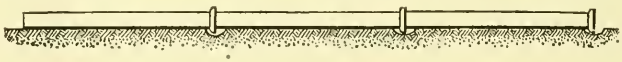


FIG. 87.—Bell holes in trench bed.

If the foundation is soft the pipe should be laid on a concrete or gravel base. For ordinary soils the only precaution the inspector need take is to prevent back-fill under the pipe.

Unless the foreman is alert the trench is often excavated too much in some places, which are then back-filled. This is bad practice except where boulders are encountered which must be removed and the cavities back-filled with good material.

Pipe.—The pipe is inspected for flaws; it is then placed in the trench with the bell end upstream. At each joint the spigot end is placed in

the bell and forced against the shoulder, making a tight joint. The pipe is then lined correctly and a gasket of jute or oakum driven into the joint with an iron calking tool having a 2- to-3 in. offset, as shown in Fig. 88. The balance of the joint is then filled with a 1 to 1 cement mortar.

The trench is then back-filled, care being taken not to throw the pipe out of line: the back-fill must be well tamped in layers not exceeding 6 in., using heavy paver's rammers. A good working rule is to use two of the best men on the job tamping and the laziest man on the force throwing dirt to them.

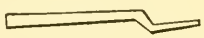


FIG. 88.—Caulking tool.

Head-walls for Culverts.—The face of the head-wall should extend beyond the end of the pipe, as it is difficult to get a good looking connection if it is flush with the end.

Figure 89 shows a convenient plug form for this extension. This plug is set into the end of the pipe and can be readily removed; the

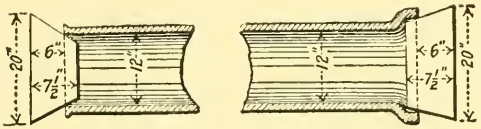


FIG. 89.—Flare plugs for pipe headwall forms.

resulting head-wall being pleasing in appearance. The head-wall form can, also, be readily skewed (set at an angle with the pipe) if required.

Reinforced Concrete Pipe.—Pipe of this character is laid in the same general manner as cast-iron pipe with the following minor changes. It is desirable to dig the trench 2 or 3 in. lower than necessary and back-fill with gravel well tamped to give a slightly flexible bed for the pipe. It is essential that concrete pipe be handled with care as most of the damage to this pipe occurs by careless handling. Pipe up to 18 in. in diameter can be easily handled by rope slings held by hand. For 24-in. or larger pipe a tripod with chain block hoist is desirable to prevent breakage in lowering with the trench and to avoid needless disturbance of the bed by dropping heavy pipe at an angle. The back-fill for this kind of pipe must be very carefully done up to half height. In loam, clay and quicksand soils it is desirable to cradle the lower half of the pipe with concrete 1:3:6 mix.

CONCRETE CULVERTS

Excavation.—The trench is dug to the required depth; if the material will stand vertically no back forms are necessary, and the width of the trench is made the width of the out to out dimensions of the culverts. If back forms are needed the trench is usually made 2 ft. wider. If running water is encountered which cannot be temporarily dammed, or diverted, the trench is made wide enough to flume the stream through

on one side of the back forms for small culverts, or between the abutments for larger span structures.

Back-fill.—The back-fill is made as for cast-iron pipe except that it should not be deposited on the fresh top of a culvert within 24 hours of laying the concrete.

Forms.—Forms should be true to shape and constructed of planed tongue and groove or carefully sized lumber, for the exposed surfaces. Face form lumber should never be less than 2 in. thick and should be well ribbed. They should be water-tight, as otherwise the fine material will run out of the face of the concrete and leave a rough "pop-corn" surface. They must be well braced to prevent bulging. Triangular or feather-edged grooved moldings are placed in the angles of the forms to shape them satisfactorily.

Removal of Forms.—The length of time that the forms should remain in place is a matter of judgment; it depends upon the cement and weather conditions.

The author's practice is as follows:

Head-walls or parapet forms are removed within 36 hours in dry weather or within 48 hours in damp, cold weather, in order to rub down the surfaces.

Low side-wall forms for spans of 2 to 3 ft., where the deck is constructed later, may be removed in 36 to 48 hours.

Trunk forms for small culverts 2- to 3-ft. span may be removed in from 3 to 7 days.

Trunk forms for medium culverts up to 10-ft. span 7 to 14 days.

Deck forms for spans above 10 ft. may be removed in from 14 to 28 days.

Any unusual load, such as a roller, should not be allowed over a new culvert of even a small span in less than 7 days, unless precautions are taken to distribute the pressure by planking the back-fill, or otherwise, and on the larger structures a time limit of 3 to 4 weeks is advisable.

Amount of Cement, Sand and Stone Required.—Table, page 305, gives these amounts for 1 yd. of concrete.

MIXING AND PLACING CONCRETE

The strength of the concrete depends largely upon the thoroughness of the mixing and the water content.

The author's practice has been as follows:

Hand-mixing. Cement and Sand.

3 turns dry..... 3d class concrete (foundations and side walls)
4 turns dry..... 2d class concrete (decks and parapets)
Add water and mix mortar.

Drench stone and turn stone and mortar.
3 times for third class concrete
4 times for second class concrete

Machine Mix. Minimum 1 minute (15 revolutions).

Deposit in forms by dropping. Do not cast, as this separates the coarse and fine material. Use enough water to give a mixture that quakes like liver under the rammer (about 5 to 6 gal. per sack of cement).

Deposit in layers not over 6 in. deep and ram each layer thoroughly; spade the concrete thoroughly, and work an excess of the fine stuff to the face of the forms by prying the larger fragments back from the form with a narrow spade or broad-tined fork.

Machine Mixing.—Culverts generally contain such a small quantity of concrete that machine mixing is often not used although a small mixer is very convenient and the one bag batch size is in very common use for work of this character. In case a batch mixer is employed, the inspection is simplified to checking the quantities of cement, sand and stone in each charge regulating the water content and insisting on complete mix. At least a minute in the drum. If a continuous mixer is used it is well to keep watch of the cement hopper, as the cement is liable to run low, feeding only a portion of the work, or a large lump of cement may ride on top of the worm and hinder the feed; or the worm may become coated with damp cement which reduces the capacity. If the inspector watches the cement hopper the contractor will tend to the sand and stone hoppers. Continuous mixers are usually prohibited on account of the uncertainty of the resulting product.

Finishing Concrete.—If a smooth, marble-like surface is desired it can be obtained by rubbing down the surface before it has fully set with a cement sand brick moistened with water. If a rough sandpaper-like finish is wanted it can be secured by rubbing with a wooden float moistened with water. This finish is not as apt to hair-check as the smooth finish.

Freshly laid concrete should be protected from a hot sun by covering it with canvas, or blankets, and wetting it down frequently for 4 or 5 days. No plastering of surfaces should be allowed after the cement has set. If, however, it has been badly hair-checked from heat the defect can usually be remedied by rubbing with a carborundum brick. Freshly laid concrete must be protected from frost. A satisfactory method is to cover with canvas and a thick layer of manure or straw. If the concrete has been frost-pitted, on the surface only, bush hammering will give a rough stone finish, pleasing in appearance. No culvert work should be allowed in continued cold weather, as it is difficult to get a good finish and in roadwork there is no necessity of doing this work in the winter. *Concrete culvert inspection must be continuous.*

Rough Grading.—By rough grading is meant all of the work preliminary to the finished shaping, and includes moving practically all the dirt that is to be handled. It is particularly important to supervise this stage of construction, as it is here that the constructing engineer regulates the placing of the best material in the center (under the metalling) and the poorer materials on the sides.

In order to grade economically, the contractor and inspector should each be furnished with lists similar to those given below (Fig. 90), showing, in a convenient form, the amount of excavation station by station and within what bounds it is to be placed.

Cuts.—For cuts over 3 ft. deep slope stakes are placed and care taken that the slopes are properly carried down. If excavated beyond the finished lines it is practically impossible to make a back-fill that will hold and the resulting irregularities are unsightly. This is impossible where a steam shovel is used in which case the slope is cut to the half slope line and the upper earth plowed down to complete the lower portion in fill.

Excavation Summary

Sta. to Sta.		Exc.	Emb.	Waste	Borrow
123	134	476	375		
134	140	286	240		
140	157	642	662		>185
157	178	766	629		
178	179	231		231	
179	186	298	244		

Detail Quantities

Sta. to Sta.		Exc.	Emb.
123	123+50	575	225
123+50	124	150	900
124	124+50	—	1450
124+50	125	150	900
125	125+50	320	200
125+50	126.	170	500
126	126+50	30	925
126+50	127	30	650
127	127+50	260	410
127+50	128	350	250
128	128+50	635	160
128+50	129	635	75

Lists

Remarks
Quantities in cu. yds.
Haul from Sta. 179 to 150
Quantities in cu. ft.

FIG. 90.— Earthwork record to show direction and limits of moving excavation.

Fills.—For fills slope stakes are set in the same manner as for cuts.[1] The earth should be deposited in thin layers, 6 to 8 in. deep, extending from slope to slope, and each layer well compacted either with a roller or by driving over it with wagons in the process of building. Where the old surface has a steep slope it must be plowed to give a good bond with the new fill and prevent slide.

It is bad practice to build the center of the fill and then shovel loose material off of the edge to widen the slopes, as this loose side-fill is not compacted and under the action of frost will nearly always slough away from the harder central portion.

[1] Slope stakes can be located directly from the templet cross-section which is a much easier method than the railroad practice of rod and level computation.

To get the full benefit of the teaming in compacting the dirt, a deep fill should be started at a point nearest the cut from which the material is hauled and each load driven over the loose layer. In this way nearly every fill can be better compacted than by the use of a roller alone. For long fills where there is considerable teaming over each layer a roller is not usually needed.

Wet clay or heavy loam should never be placed in the bottom of a fill, as it dries slowly when not in contact with the air and keeps the fill "spongy." The writer has seen cases where fills not over 3 ft. deep have remained soft for 2 months where wet material had been used and it was finally necessary to remove it.

Transferring Grade from Stakes.—A handy level for transferring the grade from stakes to the center of the road is shown below. If well made and properly used it will transfer the grade elevation 50 ft. with an error of less than 2 in., which is close enough for this stage of the construction: Its proper use depends on its being located midway between stake and hand. If held close to the hand the grade transfer will always be low due to sag of the string.

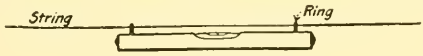


FIG. 91.—String level.

Ditches.—The ditches *must always* be dug out enough to protect the center grading before the fine grading (stone trench) is completed, and it is usually cheaper for the contractor, as well as better for the road, to dig them out before the fine grading begins.

Regulation of Material in Fills.—In fills, particularly shallow ones, the road can be greatly improved by a judicious selection of available materials. Material taken from two nearby cuts, or at different depths in the same cut, will often vary in character and the most experienced man on the job should indicate which materials to use in the center of the fill, under the metalling, and which on the sides. The soils in the order of value for fills are gravel, coarse sand, loam and clay. For shallow fills on a good foundation clay should not be used under the stone, and a good material must be overhauled or borrowed. It is better to avoid overhaul if possible, as it is an item liable to be disputed as to the amount. Where it is necessary, a good practical method of determining the amount of the small quantities of earth usually needed is to keep track of the number of wagon loads overhauled from station to station.

Sod may be used in the sides of the fill, but should be kept at least 3 ft. outside of the pavement edge. It should *never* be used as a shoulder close to the stone or in the center of the fill under the metalling.

The author wishes to emphasize the importance of this regulation of material. At present the inspection of rough grading is often confined

to keeping the sod from the center fill, and the center fill is made of the dirt just as it happens along. As a result, the subgrade will vary greatly in character and if a uniform depth of stone is used over this "spotty" fill the results are often not satisfactory, while if the depth of stone is varied to meet the subgrade conditions an unnecessary amount of stone is used. In cases where there is no choice of earth materials the stone depth must be made thick enough to meet the requirements of the grade.

FINE GRADING FOR STONE TRENCH

The fine grading includes the shaping and consolidation of the stone trench.

The construction shoulder must be at least 2.5 ft. wide and well consolidated in order to hold the stone solidly during rolling. This must be watched continually by the inspector as it is a point often slighted.

Shaping the Grade.—A simple guide for shaping the grade is shown in the accompanying sketch (Fig. 92) and consists of three strings (center and sides) stretched between pins driven at least every 50 ft. and prefer-

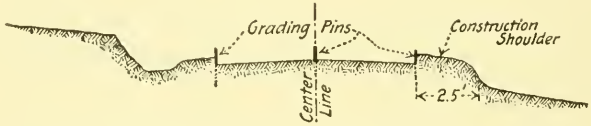


FIG. 92.—Convenient system of grading lines for fine grading.

ably every 25 ft. The pins should not be placed at intervals of more than 50 ft. as this will cause objectionable sag in the lines and the grade will be undulating. On vertical curves at summits the pins should be placed from at 12- to 25-ft. intervals. The grade elevation is transferred and the lines carefully set at their proper elevation by means of a straight-edge, level and rod, or by stretching a line between grade stakes on opposite sides of the road as previously described. The string level recommended for rough grading cannot be used, as it is not sufficiently accurate.

The general level of the finished consolidated grade should be correct to within 1 in. This leeway of 1 in. from the figured grade makes it possible to get satisfactory results without wasting time on finical work and does not appreciably affect the total amount of excavation, as the errors tend to balance. There should, however, be no short, small irregularities of grade noticeable to the eye. Continuous inspection on shaping the grade is not necessary.

Consolidating the Grade.—Most soils when slightly moist will consolidate readily if thoroughly rolled. Clay, heavy loams or excessively fine sandy loams (quicksand) will not pack when wet. Continued rolling is injurious for these soils in this condition, as they will "work" under the roller. If they occur only in small pockets they can be removed

and replaced with good material; if in stretches of any length the grade must dry out before placing the stone. Under drains are constructed at this time, where necessary, and the surface ditches are cleaned out and made effective. Where a hard shower has softened the surface only of a previously consolidated grade of this kind and the contractor wishes to lay stone, the surface can be hardened by spreading a thin layer of gravel or waste ¾-in. stone and rolling it into the earth. This will help in preventing the stone teams from cutting up the grade.

Gravels and finely pulverized clay, or clay loams (deep dust), will not consolidate when dry; such material must be thoroughly sprinkled to get a compact grade. It is not, however, customary to sprinkle coarse gravels, even if slightly loose, as no objectionable results follow from placing stone on such a grade; deep clay or loam dust is objectionable and must be sprinkled.

Coarse sand makes an ideal foundation but is hard to keep in shape while placing the first layer of stone. In some cases sprinkling will harden it sufficiently; in others a layer of fine loam has been spread over the sand and flushed in with satisfactory results. Sometimes where loam is not available a cheap cheesecloth has been spread over the top of shifting sand to prevent the stone from punching in too much under the roller. The author has never encountered any coarse sand that could not be successfully treated by sprinkling and covering with 1 or 2 in. of ¾-in. stone; the blanket of ¾-in. stone prevents the sand from squeezing up into the loose bottom stone and spreading the fragments.

While coarse sand makes a good foundation, a fine sand or sandy loam approaching quicksand is very treacherous; it is difficult to judge the degree of fineness at which a sand becomes treacherous, particularly when it is dry. A sieve test can be made (not over 30 per cent should pass a 100 sieve), but a good practical method in the field is to saturate the material thoroughly with water; a satisfactory sand becomes more compact while an exceedingly fine sand gets "quaky."

Determination of Stone Depths and Construction of Subbase.— Practically the only engineering problem that the constructing engineer has to solve is that of foundations. It is recognized by most designers and estimators that it is impossible from even a careful preliminary examination of the soil to specify exactly the amounts and depths of foundation stone. To meet this an extra quantity of subbase or bottom stone is allowed the constructor, to be used as he sees fit. During the progress of the rough and fine grading the exact limits of the different kinds of subgrade soil are determined and the stone depths varied according to his judgment (see page 82). Men that really understand this part of the work are hard to get, as it is only from extended experience and intelligent study of their own failures and successes that a sound judgment is developed. An examination of Table 17, page 100, will help a beginner.

A good constructing engineer is much more difficult to find at present than a good technical designer.

Where subbase is used the subgrade is dug out to the required extra depth and rolled if it is in such shape that it will not "work." Peat, muck, wet fine sand or wet clay cannot be rolled until the subbase is placed and filled. Where it is possible, such soils should be drained and allowed to dry before placing the base, but is often not feasible to dry them enough to allow rolling, even though underdrainage is put in, which partially hardens them and successfully protects the road after the stone has been placed. This is particularly true on flats where it is hard to get an outlet for a drain or in the fine sands on which an underdrain has little effect on account of the capillary action of the material. Where a soft subgrade of this kind is encountered, a stony gravel makes the best subbase, as it contains no voids between the larger fragments and when rolled the soft underlying material cannot squeeze up through the course. In case boulder or quarry stone base is used on a soft grade, it is necessary to lay them in close contact by hand and then fill the voids completely with gravel or No. ¾ stone *before* rolling; otherwise the subgrade material would squeeze up between the stones, separating them and partially destroying the efficiency of the base.

In the spring and fall of the year it is common to find good material so saturated from long-continued rains that it acts badly under the roller and instead of waiting for the grade to dry out, when the normal thickness of stone would be sufficient, subbase is often put in either to help the contractor so that he will not be delayed or because the engineer is misled as to the character of the material. This results in a waste of money. On the other hand, clay, when thoroughly dry, is hard and firm, which often influences a new man to omit subbase where it will surely be needed.

The use of subbase should not depend too much on the action of the grade under the roller unless the degree of saturation of the material is considered, although it serves as a guide in locating doubtful spots. The final determination should depend on test pits, which develop the character of the underlying material.

The subbase is constructed, as explained, under Foundations, either of gravel, boulder or quarry stone. The depth is gauged by lines. The ratio of loose to rolled depth is given on page 195.

Continuous inspection is not needed on subbase; the depth of grading is checked before the stone is placed and the width, depth and workmanship can be readily determined after the base is completed, and by an occasional inspection during the progress of the work.

Bottom Stone.—The earth subgrade must be firm and compact before the stone is spread. Bottom stone must *never* be laid on a soft grade. One of the most common slips of inspection is to allow this

to be done and the result is a "punky" bottom course that is never up to standard. The distributing power or this course depends largely on the stone fragments being firmly interlocked; if the stone is placed on a soft grade and rolled, the earth will squeeze up between the fragments and separate them.

The depth of the loose stone is gauged by the lines or cubical wooden blocks placed on the subgrade. Blocks are more convenient than lines except over subbase of stone fills, where lines must be used to get a spread true to shape and grade. The ratio of loose to rolled depths is given on page 193.

The loose stone is rolled until the stones are solidly interlocked and there is no movement under the roller. A thin layer of satisfactory filler (see materials page 208) is spread over the top, rolled and broomed in; the process is repeated until the stone is thoroughly filled. Continuous inspection on bottom course is not necessary. The widths and depths can be readily checked by ocasional inspection. The three points to be carefully watched during construction are: (1) That the grade is firm; (2) That the loose fragments are thoroughly rolled *before* the filler is applied. (3) That the finished surface is true to shape and grade as a permanently smooth top course cannot be constructed over a humpy bottom; the top course must be uniform in thickness. A great many inspectors believe the contractor when he tells them that he can smooth up the job with the top course. He can temporarily but the second season the result is Hell.

It is desirable to complete the bottom course well in advance of the top, in which case the contractor can work to advantage after rains, and the course will be better compacted by subjecting it to some traffic action.

Where local stone is crushed on the job and the stone used ranges in size from 1 in. to tailings, care must be used in spreading that the sizes are well mixed, as pockets of fine or coarse stone are objectionable. The simplest method of mixing is to run the different sizes into one bin at the crusher; if they are separated they can be well mixed by loading one end of the wagons with the 1¼ to 2½ in. and the other end with 2½ to 3½ in. and when dumped on the grade they will run together. When difficulty is experienced with these methods in obtaining a well-mixed stone spread the loose stone can be harrowed. Many specifications call for harrowing thoroughly where a large range of crushed stone size are allowed in one course. If possible, tailings should be used as subbase. When used in the bottom course having a rolled depth of 4 or 5 in. they should be placed in the lower part of the course, but for a 3-in. depth they should be placed on top and broken with a knapping hammer into fragments of less than 3½ in.

The filler should not be dumped directly on the stone unless absolutely necessary. Drawing the loads onto the unfilled stone loosens the course,

and, also, at each pile of filler there is apt to be left an excess which is hard to clean off.

The approximate amount of filler required per 100 ft., and the spacing of 1½-yd. loads as given below. The amount varies for the different materials used.

Grading and foundations have been treated at some length, as they are the most difficult parts of the construction.

TABLE GIVING THE APPROXIMATE AMOUNT OF FILLER REQUIRED PER 100 FT. OF ROAD FOR CRUSHED STONE MACADAM BOTTOM COURSES OF DIFFERENT WIDTHS AND DEPTHS, USING 0.35 CU. YD. OF FILLER PER CUBIC YARD OF ROLLED BOTTOM

(In cubic yards)

Width of macadam, feet	Rolled depth of bottom course			
	3 in.	4 in.	5 in.	6 in.
10	3.2	4.3	5.4	6.6
12	3.8	5.1	6.5	7.6
14	4.5	6.0	7.5	9.0
15	4.9	6.4	8.0	9.9
16	5.2	6.9	8.6	10.4
18	5.9	7.9	9.7	11.8
20	6.4	8.6	10.8	12.8
22	7.0	9.4	11.8	14.2

TABLE GIVING THE APPROXIMATE SPACING OF 1.5 CU. YD. LOADS OF FILLER FOR THE WIDTHS AND DEPTHS SHOWN IN PRECEDING TABLE

(In feet)

Width of macadam, feet	Rolled depth of bottom course			
	3 in.	4 in.	5 in.	6 in.
10	46	34	27	23
12	40	30	23	20
14	33	25	20	17
15	31	23	19	15
16	29	22	17	13
18	25	19	16	12
20	23	18	13	11
22	21	16	12	10

Waterbound Top.—Waterbound top is constructed in the same way as the bottom course except that stone dust is used for a filler and the course is puddled as has been described.

If the stone used is a local stone crushed on the job the output of the crusher must be carefully controlled, especially when selected boulders are used, as it is very important that the size and quality of such stone shall be uniform.

Imported stone can be inspected on the cars. Aside from this, comparatively little inspection is required except at the stage when the loose stone has been rolled and before the binder is spread. At this time the inspector should examine the rolled course very carefully to see that it is true to shape and has no short depressions or humps. The smooth riding quality of the road depends on this inspection and too much care cannot be taken. This point is particularly emphasized, as many of the stone roads in New York State have been criticized as rough for automobile traffic. Any depressions are filled with stone of the same size as the body of the course and rolled, after which the course is again inspected and corrected until it is made true. The binder is then spread, broomed in dry, and puddled. In puddling use plenty of water and roll rapidly.[1] If a pipe line and hose are used a pressure of 100 to 125 lb. at the pump should be maintained. The road can be conveniently puddled in stretches of 100 to 200 ft.

After the road has dried out and been opened to traffic, if raveling occurs it can usually be remedied by light sprinkling and rolling.

Where the top course is granite, gneiss, or trap, it is often necessary to use a certain percentage of limestone dust with the normal screenings. The limestone is more effective when spread last, filling the top voids of the course.[2]

General Maintenance Methods.—Detail maintenance methods and costs are given in Chap. IV.

Well-defined holes are repaired by cutting out the edges square and vertical, filling with regular top stone, rolling and puddling as in original construction. Small depressions are usually remedied by filling with cold patch or screenings and oil. Surface pitting is remedied by oiling and cover. Shoulders are built up by scraping fresh dirt or by the addition of gravel or stone. The maintenance of ditches, guard rail, culverts etc. is procedure similar for all types of improvement.

[1] For amount of water see page 209.

[2] For amount of limestone screenings see page 209.

PENETRATION BITUMINOUS MACADAM PAVEMENTS

Bituminous macadam is what the name implies, a macadam pavement bound with bituminous material. The larger stone fragments, ranging in size from 1¼ in. to 2½ in., depending on the depth of the course, are spread and rolled; a heavy grade of refined tar, residuum bituminous material, or fluxed natural asphalt, is then poured hot, either by hand or machines into the voids of the stone so that the stone fragments are covered with a thin coat of bituminous material; ¾-in. stone, or dustless screenings are spread over the surface and broomed and rolled until the voids are filled; if a bituminous flush coat is to be used the excess filler is broomed off and the surface application of bitumen completed. Where the flush coat is not applied, a wearing coat of clean screenings is spread over the surface.

FIG. 93.—Penetration bituminous macadam on primary state highway carrying approximately 1,800 vehicles per day (10-hr. count in summer). Note the easy shoulder slope which adds to the safety of traffic.

The amount of bituminous material used as binder varies from 1.50 to 1.75 gal. per square yard, depending on the depth of the course. The amount used for flush coats ranges from 0.2 to 0.5 gal. per square yard. Standard specifications are given on page 248.

Penetration bituminous macadam pavements are satisfactory and economical under normal traffic conditions ranging from 800 to 2,000 vehicles daily (10-hour count in the summer season). They have been used quite extensively for traffic as low as 300 daily and in a few cases with moderate success up to 6,000 daily but caution should be exercised in their

selection for roads carrying more than 2,000 daily. The essential advantage of this type lies in its ability to provide very satisfactory road service at less initial cost than any type of rigid pavement. Under moderate traffic their final cost including maintenance and renewal compares favorably with any type of road. When well designed and constructed with

FIG. 94.—Penetration bituminous macadam on resident village street. A very excellent use for this type of pavement.

thicknesses recommended in Chap. II, page 100, they can be utilized in the future as a base for higher type surfacings. They are a very satisfactory type for Class II traffic and for residential village and city streets. They are not seriously damaged by settlement and can be easily and

FIG. 95.—Texture of surface well constructed bituminous macadam. Photo taken after 7 years' use, Class II traffic main road, New York State.

quickly repaired. They are safe for high speed travel; they ride well if carefully constructed but under careless inspection where the bitumen is unequally applied, they gradually develop humps and hollows very disagreeable to fast traffic. This type of pavement requires careful construction and ample stone depth. They are resilient under steel tire

traffic as well as under ordinary motor traction. They are used extensively in England for this reason. They have a pleasing neutral color.

Bituminous macadams including base and top range in initial cost (1922 cost conditions) from $1.60 to $3.40 ($2.20 average) per square yard depending on varying conditions of foundation soil, traffic and local materials; the maintenance charge will range from $0.02 to $0.06 per square yard per year, depending on all sorts of conditions and the surface renewal charge distributed over the life of the pavement will probably average about $0.10 Class III traffic, $0.12 Class II traffic to $0.20 Class I traffic per square yard per year, 1922 cost conditions.[1]

The use of excellent materials is desirable but for the type of traffic usually served best by this pavement (Class II), excessive refinements of materials or manipulation which raise the cost needlessly may well be avoided. Materials, details of design and the essentials of inspection are later discussed. The following designs can be used with assurance of reasonable success.

Recommended Design.—The recommended designs represent conservative practice. A large mileage of thinner pavements have been constructed and have served quite satisfactorily for considerable terms of years under favorable traffic conditions. As a matter of fact, it is rare that any well-constructed bituminous macadam road of 80 per cent of the thickness recommended is a serious failure for if traffic proves too severe for either the foundation strength or surface resistance to wear, the old pavement can be strengthened by additional stone and the pavement made satisfactory by capping with a more resistant surface at considerably less cost than required for a rigid type of pavement.

It is, however, undesirable to resort to additional surfacing in too short a period particularly on the score of depth weakness and it seems desirable to avoid much reduction in thickness below the depths recommended where local traffic laws permit a 28,000-lb. gross vehicle load limit. A surface life of 8 to 12 years is reasonable for this type when fairly well maintained under traffic of 800 to 2,000 daily although there are a considerable number of cases which do not fall within these limits (see Chap. IV).

Suitable Materials.—Materials for foundation courses were discussed under Waterbound Macadam, page 208. Top course materials are crushed stone and bitumen. Typical specifications are given in Appendix A.

Crushed Stone.—Top course crushed stone consists of three sizes usually specified as follows:

Coarse aggregate	1¼- to 2½-in. size
Intermediate size	¾- to 1¼-in. size
Dustless screening	⅛-to ¾-in. size

[1] Renewal costs based on maximum allowable Vialog coefficient of 250 without excessive maintenance (see page 150).

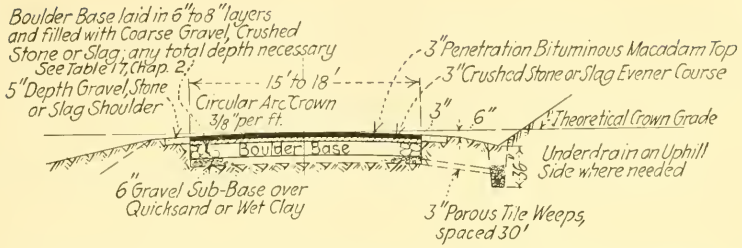


FIG. 96*A*.—Recommended penetration bituminous macadam pavement section, boulder base construction Class II or IIA traffic.

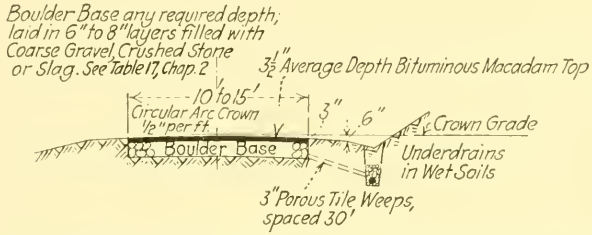


FIG. 96*B*.—Recommended penetration bituminous macadam pavement section, boulder base construction Class III or IV traffic.

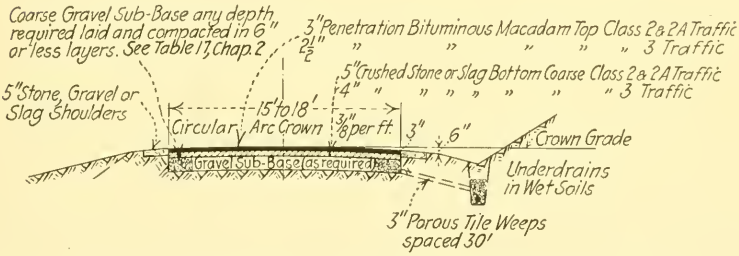

Coarse Gravel Sub-Base any depth
required laid and compacted in 6"
or less layers. See Table 17, Chap. 2
3" Penetration Bituminous Macadam Top Class 2 & 2A Traffic
2½" " " " " " 3 Traffic
5" Crushed Stone or Slag Bottom Coarse Class 2 & 2A Traffic
4" " " " " " " 3 Traffic
5" Stone, Gravel or
Slag Shoulders
15' to 18'
Circular Arc Crown
3/8" per ft.
3"
6"
Crown Grade
Gravel Sub-Base as required
Underdrains
in Wet Soils
3" Porous Tile Weeps
spaced 30'

FIG. 97*A*.—Recommended penetration bituminous macadam pavement section, gravel base construction Class II, IIA or III traffic.

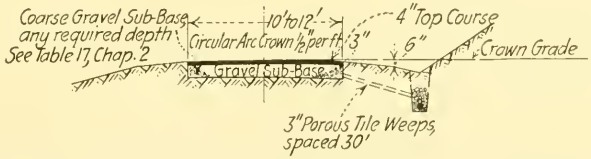


FIG. 97*B*.—Recommended penetration bituminous macadam pavement section, gravel, base construction Class IV traffic.

The stone must be hard, tough and clean. The coarse aggregate 1¼- to 2½-in. size must be uniform and must not contain over 15 per cent of stone smaller than 1¼ in. in size; this is important. Under heavy traffic where trap or the harder granites are available, a minimum French coefficient of hardness of 8 is desirable (5 per cent or less of wear). Very good results can be obtained with a minimum hardness coefficient of 7 (6 per cent or less of wear) and this is the usual minimum limit where limestones and the harder sandstones are the prevailing formation. Under light traffic and where hard rock is very expensive, a coefficient as low as 5 has been used but under such conditions it is desirable to increase the size of the coarse aggregate to 2½ to 3½ in. and to use a harder grade of rock for the screening incorporated into the seal coat.

Bitumen.—Either asphalt or refined tars of the binder grade can be successfully used. Detail specifications are given in Appendix A. For penetration bituminous macadam, the author prefers an asphalt binder. The proper consistency of asphalt binder is about the only point in design which varies with traffic and climatic conditions. The asphalt authorities believe that the following table is a safe guide for determining this requirement of asphalt binder. The author prefers 80–100 for medium heavy traffic for Western New York climatic conditions.

Variation in Penetration

Traffic	Climatic temperature		
	Low	Moderate	High
Light	120–150	90–120	80–90
Medium	90–120	90–120	80–90
Heavy	80– 90	80– 90	80–90

Amounts of Material.—The amounts required for the foundation courses are given under Waterbound Macadam, page 210.

For penetration top course our records in Western New York show that the proportion of sizes used per cubic yard of finished top (limestone aggregate) are approximately as follows:

	Per Cent
1½- to 2½-in. size crushed stone	65
¾- to 1½-in. size	20
Dustless screenings	15

The total weight of all sizes limestone specific gravity 2.7 (170 lb. per cubic feet solid) is about 4,250 lb. per cubic yard for a 2½-in. consolidated depth of finished macadam and about 4,350 lb. per cubic yard for a 3-in. consolidated depth.

The following table is data released by the Asphalt Association:

Asphaltic Macadam Wearing Course

(2½-in. consolidated thickness)

Materials	Pounds per square yard
Coarse stone	227
Intermediate stone	45
Screenings	25
Asphalt	19

Bituminous Binder.—For single coat work on steep grades, 1.5 gal. per square yard applied in one coat is satisfactory for 2½-in. depth of top and 1.75 gal. per square yard for the 3-in. depth. Where seal coats are used on the lighter grades 0.4 to 0.5 gal. are generally used. Asphalt binder for penetration macadam weighs about as follows:

Asphalt

Specific gravity	Weight, pounds per gallon
1.00	8.33
1.02	8.50
1.04	8.66
1.06	8.83

Design.—The principles of design are essentially the same as for waterbound macadam; that is, a good design considers the varying depth required for the prevailing soils, the most economical use of local materials, width, crown, and depth of top course. To determine total depths, reference is made to Table 17, page 100. Having decided on the depths required, alternate estimates are prepared on the basis of utilizing gravel, boulder or macadam foundation courses. The variations in depth of macadam over gravel or boulder bases were developed in Chap. II, page 99. The most economical combination is adopted. The important point is that a real design shall be made considering soil conditions and local material. Rigidly standardized uniform depth over varying soils is to be avoided, see Sample Design Report, page 156. Where a macadam bottom or evener course is used, it is permissible to reduce the top course to a 2½-in. thickness under fairly light traffic. Under heavy traffic, a depth of 3 in. is recommended. Some states use a 2-in. depth of top but

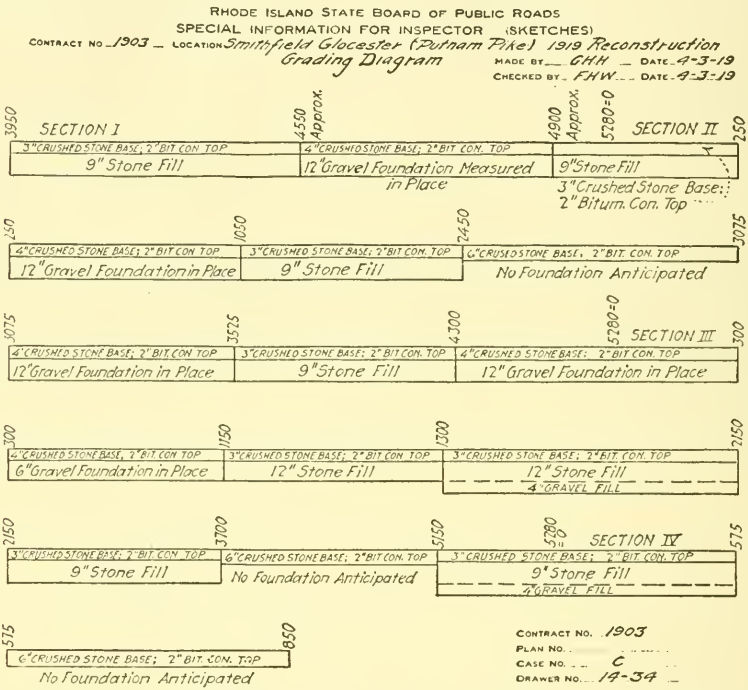


Fig. 98 shows a design chart used in Rhode Island to indicate the varying required depth of macadam for construction purposes. This is an excellent example of an intelligent effort to get a well balanced macadam design. Personally the author has never succeeded in exactly determining the limits of the different depths before grading operations were started and is inclined to leave the exact limits to the constructing engineer but it is most certainly desirable to determine the general character of the soil at short intervals at the time the survey is made by means of test holes, or bar soundings with gas pipe core samples at cut locations in order to make a rational estimate of the amount of extra foundation course required and in this way provide the constructor with an ample allowance of subbase for contingencies.

FIG. 98.—State of Rhode Island, information for inspectors.

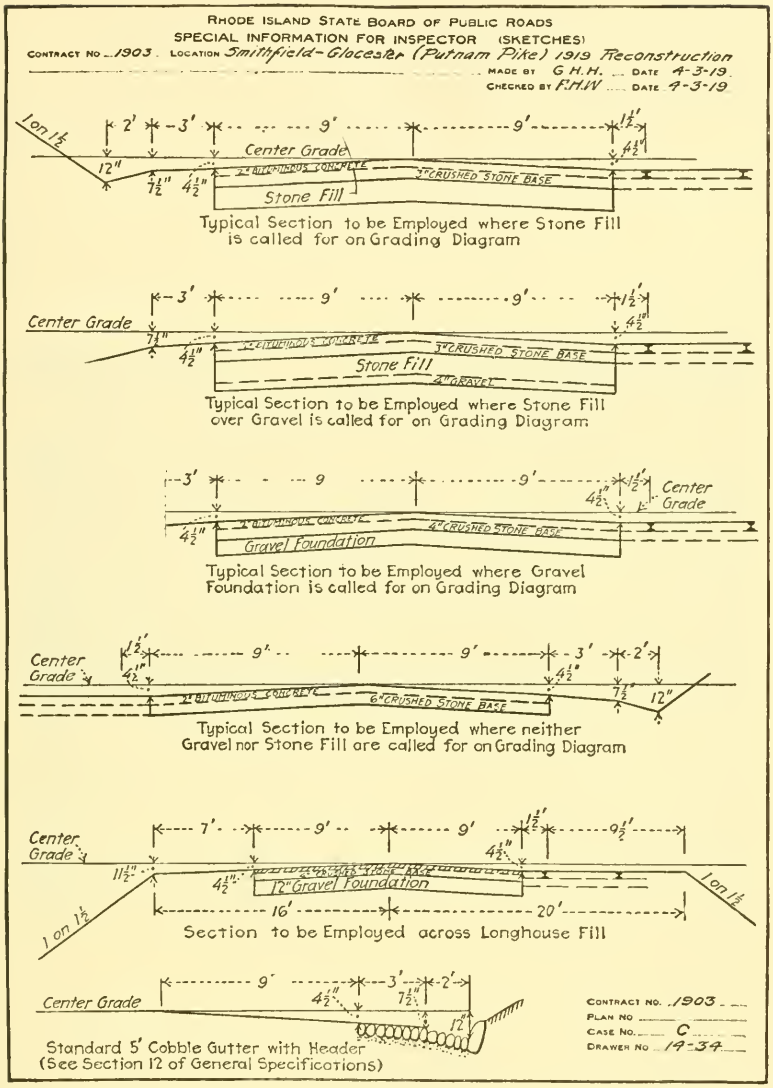


FIG. 98A —Special detail information for inspectors. Rhode Island practice (to accompany Fig. 98).

our experience has not been entirely satisfactory with depths of less than 2½ in. where a limestone aggregate is used.

Widths and Crown.—Widths were discussed in detail in the first book of the series and summarized in Chap. II. Extra widening at sharp curves is desirable, see Tables 10 to 10B, page 70. Village street widths are outlined in Appendix E.

A circular arc crown is a good form. The total difference in elevation between center and edge of pavement is usually based on ⅜ to ½ in. multiplied by the half width in feet. For the usual road 16 to 20 ft. in

FIG. 99.—Boulder base construction, heavy traffic road.

width, the slope of ⅜ in. per foot seems satisfactory. For village streets of greater width, it is just as well to use the crown recommended for sheet asphalt pavements as given on page 315.

On sharp curves on rural highways, one-way banking is desirable except on high fills. Ordinary practice in regard to banking slopes is given on page 211.

Comparative Costs.—The cost of one coat 2½-in. bituminous top, using 1.5 gal. per square yard, will range from $0.80 to $1 and a 3-in. one-coat top, using 1.75 gal. per square yard from $1 to $1.20 a square yard. The flush coat using 0.4 gal. per square yard will add about $0.08 to the above costs. For the purpose of comparison with macadam, a fair set of prices is (1922 cost conditions):

	PRICE PER SQUARE YARD
3-in. waterbound macadam top course	$0.70
2½-in. bituminous top, one coat of bitumen	0.85
2½-in. bituminous top, flush coat	0.90
3-in. bituminous top, one coat of bitumen	1.00
3-in. bituminous top, flush coat	1.10

Construction Equipment and Methods.—Construction equipment is to be handled in detail in the fourth book of this series. For the benefit

of the student, a short list of machinery and usual methods were given under waterbound macadam. The only addition for bituminous macadam is the equipment for spreading the binder and seal coat.

Bitumen can be spread by either hand methods or machine application. Machine application is generally used as it is cheaper. For surface applications, machine distribution similar to Fig. 76, page 205, is superior to hand work. For the application of the first coat or binder pour in bituminous macadam, careful hand spreading is really superior to the usually mechanical spread although there is one form of mechanical spreader controlled by the Barrett Company which has the economy advantage of machine spread and approximates quite closely the better control of the hand spread (see Fig. 102, page 242).

The successful application of binder bitumen depends on the proper coating of the coarse stone aggregate on all sides with the proper amount of bitumen. The factors which cause irregularity in the result are non-

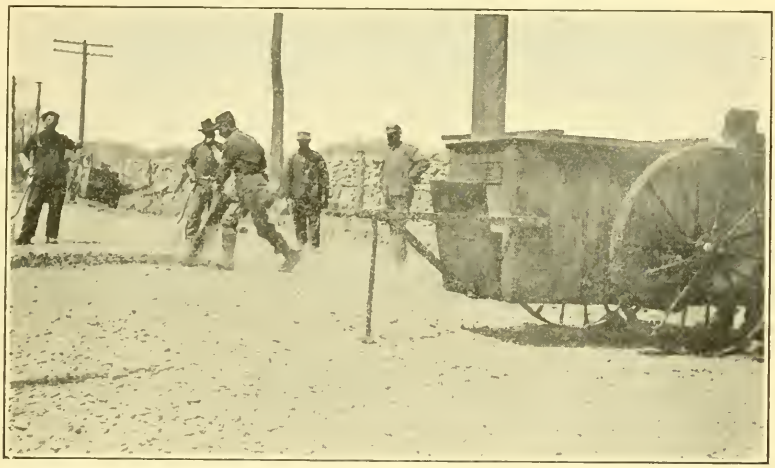


Fig. 100.—Satisfactory pour with hod spreaders. Pouring sheet is nearly vertical. The sides of the stone away from the spreader are not as well coated as on the near side. This is remedied on the return trip of the spreader. Bitumen poured at angle of 45 degrees with center line of road. Usual type of heating kettle in foreground. Can be moved ahead without disturbing stone. Five of these heaters were used on this job to keep work moving rapidly.

uniformity in the stone sizing and voids and in non-uniformity of spread which can be caused by overlap, or failure to lap, or by the direction of application of the bitumen and by lack of control as to the rate of application. Even with the utmost care, there will be considerable variation in the stone sizing and the voids as spread and unless the rate of application is varied at these unusual areas, an inferior result is obtained. Hand spreading gives much better control in varying the rate for such conditions than the usual mechanical tank spread similar to machine, Fig. 76, page 205. The mechanical equipment shown in Fig. 102, page 242,

can be manipulated to vary the spread nearly as well as the hand spreading pots shown in Figs. 100 and 101. The highest type of intelligent labor should be used for the application of bitumen.

Hand Spreading Methods.—Hand spread requires that the bitumen be shipped in barrels or drums which adds considerably to the delivery price. The bitumen is heated in small kettles preferably of the 2-barrel

FIG. 101.—*An example of how not to do it.* Bitumen too hot, note the heavy smoke. Asphalt delivered in a horizontal sheet instead of in a vertical sheet. If these spouts were turned 90 degrees so that a vertical sheet was produced, very excellent results can be obtained. Figure 95 was poured with this type of pot with vertical delivery and it has handled heavy traffic for 10 years without developing objectionable humps or hollows.

capacity (Fig. 100) which are fired with wood and can be moved by hand.

A good organization and equipment for hand application is as follows:

5 2-bbl. kettles
1 10-ton roller
4 Spreading hods or pots with vertical slot delivery.

Organization

1 Foreman
2 Pourers
5 Kettlemen
6 General utility men to open barrels, spread ¾-in. stone and screenings, move kettles, etc.

The coarse stone is spread in the same manner as for waterbound macadam, and rolled moderately firm where asphalt binder is used and with a hard firm lock if tar binder is used. *The proper amount of rolling preliminary to the application of the binder is a disputed factor but the author has had better results with a firm consolidation.* The stone, however, should not be rolled so much that it tends to break up or powder.

The bitumen is brought to the proper temperature (specified for each variety) and poured at an angle of 45° with the road center line. The rate of application is gauged by keeping track of the number of hods or pots used over a given area; in a short time the pourers become expert in

judging the spread by visual inspection and only vary slightly from the required amount; for spreading the binder coat, the pots or hods are held close to the surface of the stone; for the seal coat, they are held high and the bitumen is spread in concentric arcs with the pourer standing in the center of the pavement and swinging the pot or hod.

After the binder coat is spread, the surface of the stone is covered with a layer of ¾-in. stone clips just enough being used to chink in the voids of the coarse stone; the course is rolled once to drive these stones in and interlock them with the coarse stone; continued rolling at this time is injurious. The following morning, the excess ¾-in. stone is broomed off and the stone rolled fairly well; if a seal coat is used, it is applied at this time and the screenings added; if no seal coat is used, the screening wearing coat is applied and the top given a light rolling. The final compaction can be best obtained by rolling about two or three times over the entire area every morning for 10 days on the back work. *That is, a large amount of final rolling is necessary but better results are obtained by distributing it over a number of days rather than attempting to do it all at once.* The tendency on this type of construction is to underroll rather than to overroll and this has been the cause of considerable poor work.

Mechanical Spreading.—The manipulation of stone spreading and rolling is the same as for hand spreading. Bitumen can be shipped in cars which are heated at the delivery point by steam and the bitumen run into the tank-distributor; the tank-distributor either is kept hot by steam or by oil burners. Where the cone nozzle spread is used, the following quotation from the Barrett Company's manual describes the procedure of spreading (see Figs. 102 and 103).

SPREADING TARVIA

Many methods have been devised for spreading hot liquid Tarvia over the wearing-course after it has been properly rolled and prepared. Spreading from a tank-wagon through a single atomizing nozzle, under steam or air pressure, has proved one of the most efficient and popular forms of applying. The Tarvia is previously heated in a tank-car and drawn to the work in a tank-wagon. The tank-wagon is provided with a fire-box so that if not already hot enough the Tarvia may be brought to the right temperature. About 250°F. will be found to give the best results. It is possible, however, to spray at 200°F., though this is too cold to give good penetration. On the other hand, it is not wise to heat above 250°F., especially in open kettles where changes take place due to the evaporation of oils.

The spreading of the Tarvia, like the spreading of the stone, must be very uniform. The best man on the work should be picked out for the job of holding the nozzle and care should be taken that exactly the same quantity goes on every square yard of the road. It is usual to specify from 1½ to 1¾ gal. for application over the wearing-course. With a little practice the workman will be able to put

this on very exactly. The area to be covered by each tank should be carefully marked off and checked up.

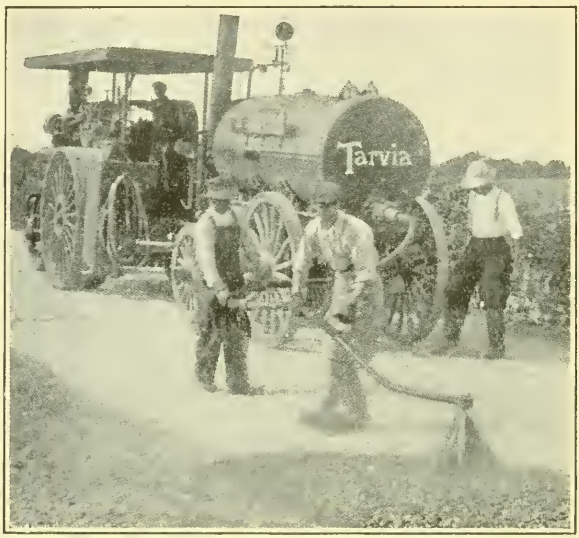


FIG. 102.—Spreading binder with the cone nozzle mechanical spreader. This is the best mechanical device available (1922) for spreading binder.

FIG 103.—Spreading seal coat with the cone nozzle mechanical spreader. The best mechanical device for seal coat is shown in Fig. 76, page 205.

In spraying the workman should proceed at a regular pace from one side of the road to the other and then immediately return.

The method of holding the nozzle is important. The workman should be instructed to hold the center of the nozzle over the edge of what was coated on the previous trip across the road. By so doing each particle of stone in the road is covered twice by the spray. Owing to the cone shape of the spraying Tarvia the stone is first coated on the back side and on the second trip on the front side. The nozzle should be held about 18 in. above the surface and kept carefully at this height. Other forms of distributing Tarvia may be used.

On small jobs the Tarvia may be heated in kettles and may be put on with hand-pouring pots. In this case great care is necessary to insure even distribution and only the best workman should be allowed to distribute the Tarvia. Each barrel should be checked up to see that the correct area is covered.

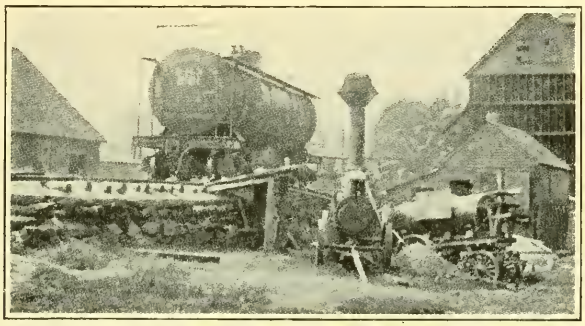


FIG. 104.—Tank car delivery. Steam heated for discharge to distributor wagon using small portable boiler.

Large auto trucks and other devices are now in the market for putting on a continuous coat of Tarvia. These may be used with economy only on jobs of large extent. They present problems of their own in distribution, owing to the care necessary to make good laps both in starting and stopping and in joining adjacent strips. If the machine laps too far it results in putting on 3 gal. to the square yard, while if the lap fails to be made the stone is bare. In using a machine for the purpose too much weight cannot be placed on the importance of proper lapping.

The spraying of the seal coat is done in the same manner as the first coat except that the nozzle is held higher from the surface (about 3 to 4 ft.). Each part of the road is passed over twice. Other methods are applicable. The pouring pot for small jobs. Auto truck sprayers apply the seal coat very satisfactorily (see Fig. 76).

Where distributors of the type shown in Fig. 76, page 205 are used, the procedure is essentially the same as for hand spreading except that extreme care must be taken to prevent overlap. The machine must be in motion when the bituminous pour is started and a uniform rate of speed must be maintained. Uniformity of spread can only be obtained by careful hand pouring of lean spots and the rate of application must be carefully checked up. Spots where an excess of bitumen occurs must be

dug out; new stone placed and hand poured. This method of spreading the binder course is a nusiance to the inspector and engineer but it is cheaper than hand methods for the contractor.

Inspection Details.—The essentials of inspection of grading, culverts and foundations were given under water-bound macadam page 217.

The main points to be controlled in bituminous macadam top are:

1. Proper size of stone.
2. Uniformity of spread.
3. Proper depth of spread.
4. Proper preliminary rolling and truing up of stone spread.
5. Proper heating and spread of bitumen.
6. Insistence on thorough final rolling.
7. Construction inspection records.

Under careful inspection, a top course of this type is a smooth riding road and should not develop inequalities of surface of over $\frac{3}{8}$ in. in 10 ft.

Practically all the inspection items have been discussed but for convenience of readers who merely refer to this paragraph without following through the preceding discussion, the essentials will be repeated.

A uniform sized clean grade of coarse stone is important. One and one-fourth to $2\frac{1}{2}$ in. is usually specified and the inspector must examine all rail shipments during unloading and as delivered on the road to see that not over 15 per cent of the stone as spread is less than $1\frac{1}{4}$ in. in size. Undersized or non-uniform stone should be rejected. In spreading the stone, small pockets of fine stone which always occur at intervals even with the best grade of aggregate must be dug out and replaced with well-graded aggregate. The depth of the loose spread must be checked. The depth of spread is usually regulated by cubical blocks of wood resting on the subgrade. The amount of stone used can be checked by railroad weights if imported stone is used. For the proper amount of coarse aggregate, see page 234. After the preliminary rolling (see page 240), a careful inspection of the course should be made for humps or hollows. This is the proper time to eliminate such defects and all inequalities in the surface must be corrected by removing a small amount of the stone or adding additional $1\frac{1}{4}$- to $2\frac{1}{2}$-in. size and rerolling. *Inequalities must never be fixed by the addition of small sized stone.* Stone spread does not require continuous inspection as all faults can be detected by examination at any time before the bitumen is applied.

A careful check must be kept on the temperature of the bitumen as overheating is very injurious and underheating spoils a free flowing spread. Temperature should be tested with a thermometer at short intervals but after a little practice, the inspector can tell by visual inspection whether the temperature is proper. If too hot, a heavy white smoke develops on pouring. If too cold, the bitumen pour is a rubbery like

sheet. Maximum and minimum temperatures are given in all specifications and vary for the material used. *The inspector must reject all overheated material as too many failures have resulted from carelessness in overheating.* Hand and mechanical methods of spreading are described page 240.

In applying by whatever method, care must be exercised to prevent frequent cases of overlap as waves or humps develop at these points. These defects do not appear for some time after the road is opened for traffic and the inexperienced inspector fails to realize the necessity for care in this particular. As soon as the bitumen is spread, the inspector must examine the spread carefully and where pools of bitumen occur (a few cases will always occur even with the greatest care), the entire top course (stone and all) must be removed and replaced with new stone,

FIG. 105.—Brooming off excess $\frac{3}{4}$-in. stone chips.

tamped or rolled and repoured. Lean spots should be given a little extra bitumen. *The inspection of bituminous application must be continuous and is vitally important in the success of the pavement.* Specifications generally state that the stone must be clean and dry. Bitumen should not be spread if the stone is dirty but practically a slight dampness is not injurious. It should not be wet but a slight dampness does no harm; a practical test is that there must be no pools of water in the bottom of the course and the stones must not be so damp that a hissing sound is produced when the bitumen is applied at a temperature of 300 to 340°. In the writer's opinion, the air temperature should not be less than 50°F., as bitumen applied in cold weather is so chilled when it strikes the cold

stone that an excessive amount is retained on the surface. As soon as the bitumen is applied a thin layer of ¾ in. stone is spread over the surface and rolled lightly; continued rolling at this point is injurious, as freshly laid bituminous tops tend to shove under the roller and form waves. The road can be thoroughly rolled and shaped to advantage only after the bitumen has had some time to harden. Good results have been obtained by rolling thoroughly the succeeding day after the binder is applied, unless in the meantime rain has saturated the course, in which case it must be allowed to dry before rolling. The roller must not be reversed suddenly. It must run easily to rest and start gradually.

FIG. 106.—Applying dustless screenings to surface of seal coat.

Before rolling is started the ¾ in. stone should be spread evenly and any excess broomed off.

The amount of bitumen spread per square yard is usually controlled by spreading a given number of pots or hods or tanks in a given length of the road. These units of length can readily be marked off by the inspector with a stick or tape. This method will be satisfactory if checked up twice a day by the number of barrels used. When the binder is heated in small kettles it will sometimes catch fire, but this is usually due to scale which has collected in the tank and if cleaned out it generally remedies the trouble. Bitumen has different volumes at different temperatures (see following table). The inspector should bear this in mind; the rate of application generally applies to 60°F. so that a correction is necessary if tanks are rated by volume capacity at spreading temperatures of 250 to 350°. The simplest method of measurement and payment is by the pound or ton weight unit bases. A volume correction table follows.

To 400°F. is approximately 12 per cent volume increase
To 350°F. is approximately 10 per cent volume increase
To 300°F. is approximately 8 per cent volume increase
To 250°F. is approximately 6 per cent volume increase
To 200°F. is approximately 4 per cent volume increase
To 150°F. is approximately 2 per cent volume increase
To 60°F. is approximately 0 per cent volume increase

Where bituminous materials are heated by steam it is often convenient to know the temperature of steam at different pressures; the following table is inserted for this purpose.

Pressure gauge, pounds per square inch	Temperature of steam, deg. F.	Pressure gauge, pounds per square inch	Temperature of steam, deg. F.	Pressure, gauge, pounds per square inch	Temperature of steam, deg. F.
15[1]	213	100	328	200	382
20	228	120	341	220	390
40	267	140	353	240	397
60	293	160	363	260	404
80	312	180	373	280	411
100	328	200	382	300	417

[1] Fifteen pounds normal air pressure; to get ordinary steam gage reading subtract 15 lb. from the values given in this table.

INSPECTION RECORD FORM

Name of Road—Pittsford-Naples.

Date—July 21, 1922.

Inspector—John Doe

Engineer—Richard Roe

Contractor—John Smith

Record of Inspection

Bottom Course—

Examined and approved Sta. 125 + 50 to 140 + 00. Two depressions Sta. 135 + 20 and 137 + 30 filled in with No. 3 stone rolled and filled.

Top Course, Stone Spread.

Sta. 125 + 50 to 131 + 25 examined and approved; no corrections necessary for depth or uniformity.

Binder Coat (Asphalt)

Sta. 119 to 124 + 10.

Official Acceptance Dated July 1, 1922.

Method—Hand spread.

No. sq. yd. covered—910

No. gallons used—1,650 ±

Rate of application—1.8 gal. per square yard.

Temperature—Max. 340°, Min. 290°

Air temperature 60° to 80°.

Seal coat — None used on this road.

Finish Rolling — Sta. 85 to 90.

Routine rolling 90 to 126.

Remarks

40 gal. bitumen rejected on account of overheating small amount left in one kettle.

Signed

JOHN DOE.

General Maintenance Methods.—For detail methods and suitability of materials, see Chap. IV.

Well-defined holes are repaired by digging out the top course for the entire depth out to the outer limits of the depression; squaring up the edges and then filling in with regular top size stone 1¼- to 2½-in. rolling or tamping, pouring with the same type of binder as the original course, adding ¾-in. stone and screenings as in the original construction. Small holes are repaired by filling in with cold patch or screenings and oil and surface pitting or livening of the bituminous binder is remedied by surface oiling using an asphaltic oil if the binder is asphalt and a light tar if the binder is a refined tar. Shoulders, ditches, guard rail etc. are routine procedure for all types of road as previously described.

TYPICAL SPECIFICATIONS. PENETRATION BITUMINOUS MACADAM TOP COURSE

52.1. Under this item the Contractor shall furnish and lay a broken stone top course composed of fragments of the specified sizes, and incorporate therewith bituminous material introduced from the surface by means of an approved pressure distributor.[1]

52.2.[2] After the bottom course shall have been completed to the satisfaction of the Engineer, a course of approved No. 3 broken stone shall be evenly spread thereon in such quantity that after the application of the bituminous material and broken stone of smaller sizes, hereafter specified, the final compacted thickness of the top course shall be as called for on the plans or ordered by the Engineer.

The No. 3 stone shall then be rolled to a firm lock by a self-propelled roller weighing approximately 10 tons, after which bituminous material of the kind specified in the proposal, heated to a temperature between 250 and 350 deg. F. if asphalt is used, and between 200 and 250 deg. F. if tar is used, shall be evenly spread over the surface. The quantity of bituminous material to be used in the first application shall be the amount ordered by the Engineer, which will approximate 1¾ gal. per square yard for a top course 3 in. thick, with a proportional reduction in the quantity for thinner courses.

The surface shall then be immediately covered with a layer of approved No. 2 broken stone, after which it shall be compacted with a self-propelled roller weighing approximately 10 tons; during the rolling process, additional No. 2 broken stone shall be applied and broomed about until the voids in the No. 3 stone are entirely filled.[3] The rolling shall be continued until the course of stone is thoroughly compacted and its surface is true and even to the established grade and conforms in all respects to the requirements specified for

[1] Hand spreading from pots or hods is more satisfactory for the first coat but not for the flush coat.

[2] No. 3 size 1¼ to 2½ in.

No. 2 size ⅝ to 1¼ in.

No. 1 dustless screenings.

[3] Too much rolling is injurious while the oil is hot; better results are obtained by waiting till the next day to compact; the course should be rolled early in the morning for 10 days and gradually hardened down.

finishing and testing the surface of "Top Course Bituminous Macadam, Mixing Method—Type 1."

52.3. After this portion of the work shall have been completed to the satisfaction of the Engineer, all loose stone shall be swept from the surface and a sealing coat of ½ gal. of bituminous material per square yard shall be applied by means of an approved pressure distributor. After this it shall be immediately covered with approved No. 1 broken stone, spread and broomed about by experienced workmen, and again rolled; the rolling shall be continued and additional No. 1 stone shall be applied until a smooth, uniform surface is produced.

52.4. Before being opened to traffic a layer of No. 1 broken stone approximately ½ in. thick shall be spread loose on the surface for wearing course.

52.5. The quantity to be paid for under this item shall be the number of cubic yards of compacted material in place in the completed course. The amount to be estimated shall be computed by multiplying the finished cross-section of the top course, as shown upon the plans or ordered by the Engineer, by the length of the top course measured along the axis of the pavement.

The price bid shall include the heating and placing of the bituminous material, the furnishing, placing, rolling and filling of the broken stone, and all labor, materials, and incidental expenses necessary to complete the top course.

This item shall not include the furnishing and delivery of the bituminous material; such furnishing and delivering will be paid for under the item covering such material.

No. 1 broken stone or gravel, chips or screenings remaining loose on the surface after the work is completed shall not be estimated as a part of the depth of the top course, but payment for these shall be included in the price bid for Item 52.

CEMENT CONCRETE PAVEMENTS

The usual concrete pavement is composed of a series of slabs separated by expansion and contraction joints. The concrete is generally the same mix for the entire depth although some pavements have a special rich surface mix. Varying amounts of steel are used in the form of dowels, corner bars, tie bars and mesh. Modifications of this type are constructed such as Hassam concrete and concrete with thin bituminous surfaces. Specifications on page 294 summarize the detail methods of construction. A large mileage of concrete pavement has been constructed on rural highways within the past few years and has met with popular approval.

From the engineering standpoint, concrete pavements are an excellent type for moderately heavy traffic (2,000 to 5,000 vehicles daily, 10-hour

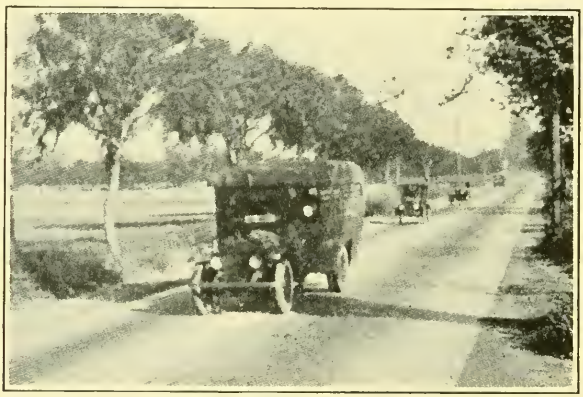


FIG. 107.—Modern cement concrete pavement on heavy traffic road (Class I). Note longitudinal central joint.

count in the summer season). They have a gritty surface which is safe for high-speed travel. They ride well if carefully constructed but under the usual inspection they are often rather bumpy and on grades of over 5 per cent it is very difficult to get a smooth riding pavement even with the greatest care. They have a bad glare in bright sunlight but are easy to follow at night. For village or city streets, they do not look as well as pavements having a more neutral color and in case they are used on curbed streets, a high curb should be designed to permit future surfacing on top of the concrete. Concrete pavements cost from $2.50 to $4 per square yard ($3 average) (1922) for new construction; the maintenance charge will range from $0.003 to $0.030 per square yard per year depending on all sorts of conditions and the surface renewal charge distributed over the life of the pavement will probably average about

$0.10 to $0.14 per square yard per year, 1922 cost conditions.[1] They are an excellent type for the lower limit Class I roads or the higher limit Class II roads where there is no large percentage of steel tire traffic but from an economic standpoint they should be used with caution for traffic of less than 1,500 vehicles daily. They are more suitable for country highways than for city or village streets except alleys.

Concrete pavements give the advantages of the rigid pavement type generally at less initial cost than other standard pavements provided care is taken not to spend too much on refinements. When surface failure occurs, they can be used effectively as a base for any of the standard paving surfaces. *The essential advantage of the concrete pavement lies in its temporary use as a surfacing and its comparatively permanent value as a rigid base.* To derive the most benefit from this combination of uses, it is necessary to avoid excessive expenditure on refinements which have only a minor effect in increasing the life of the surface. A design which results in a surface life of 8 to 15 years depending on traffic volume seems rational for this type considering the cost and the doubtful success of attempting to increase this period. This requires the use of excellent material and careful manipulation but it does not require laboratory standards of mixing and curing nor does it require the extreme refinements of true reinforced concrete design.

The cost of concrete pavements has been gradually increased by various refinements in materials, richness of mix, care in curing, joint details, reinforcement, etc. The object of all the refinements above 1:2½:5 concrete suitable for paving base of two course pavements is to produce a wearing surface for traffic which will serve satisfactorily for a reasonable length of time before recapping with some standard form of renewable surface. Eventually all concrete roads will probably serve as bases for asphaltic concretes, brick, asphalt block, stone block or some form of repairable surface. It seems probable that we have about reached the limit and in some cases exceeded the limit of justifiable expenditures for additional refinements in design and construction. No matter what care is taken, spauling at joints, surface scale and pitting, vibratory disintegration and weather action produce a rough unsightly surface in a comparatively short time and it seems good policy to get merely a reasonably good concrete of adequate depth with the idea of resurfacing as it is needed. The practical limitations of materials, manipulation, etc. to carry out this general policy are the subject of considerable disagreement but the following data can be used with assurance of reasonably good results.

Recommended Design (Concrete Pavements).—The recommended designs represent conservative practice. A large mileage of thinner roads

[1] Renewal costs based on maximum Vialog coefficient of 250 without excessive maintenance (see page 150).

has been built and has served quite satisfactorily for short periods of time. Any well-constructed concrete road of $6\frac{1}{2}$-in. average depth or more cannot be a serious failure for if the traffic proves too severe a test for the concrete as constructed, it can be protected and strengthened by capping with some standard form of surface which will make the road suitable for the heaviest modern loads.

It is, however, undesirable to resort to additional surfacing in too short a period, particularly on the score of depth weakness, and there

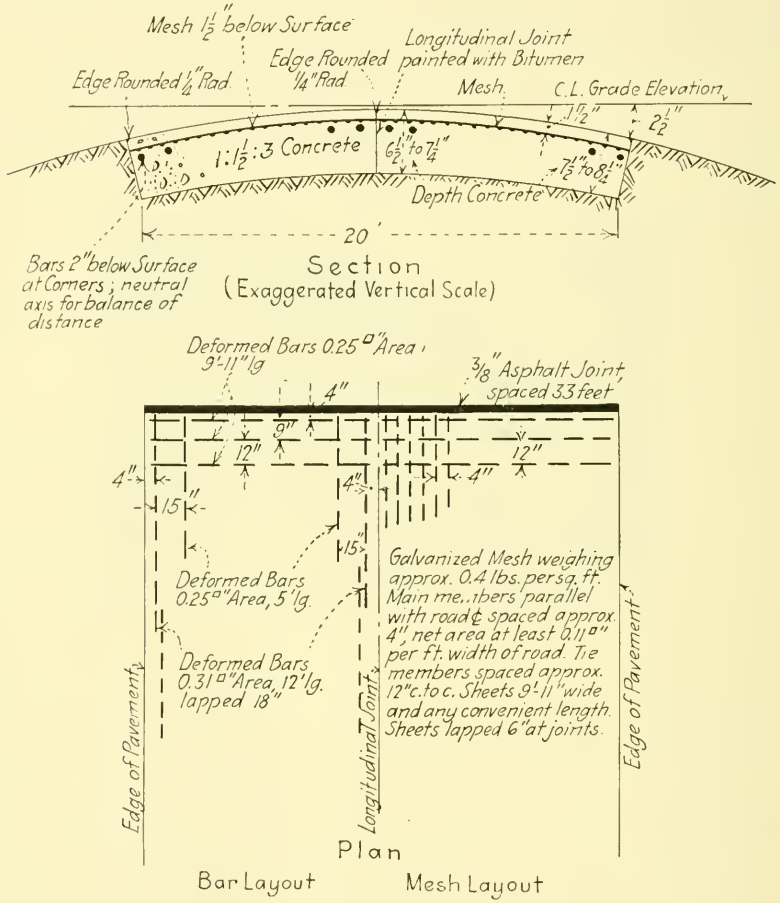

Mesh 1½" below Surface
Edge Rounded ¼" Rad.
Edge Rounded ¼" Rad.
Longitudinal Joint painted with Bitumen
Mesh.
C.L. Grade Elevation
1½"
2½"
1:1½:3 Concrete
6½" to 7¼"
7½" to 8¼"
Depth Concrete
20'
Bars 2" below Surface at Corners; neutral axis for balance of distance
Section
(Exaggerated Vertical Scale)
Deformed Bars 0.25 □" Area, 9'-11" lg.
⅜" Asphalt Joint, spaced 33 feet
4"
9"
12"
12"
4"
4"
4"
15"
15"
Deformed Bars 0.25 □" Area, 5' lg.
Deformed Bars 0.31 □" Area, 12' lg. lapped 18"
Galvanized Mesh weighing approx. 0.4 lbs. per sq. ft. Main members parallel with road ℄ spaced approx. 4" net area at least 0.11 □" per ft. width of road. Tie members spaced approx. 12" c. to c. Sheets 9'-11" wide and any convenient length. Sheets lapped 6" at joints.
Edge of Pavement
Longitudinal Joint
Edge of Pavement
Plan
Bar Layout
Mesh Layout

Fig. 108.—Recommended Design 1.

seems to be considerable doubt as to the advisability of reducing strength below the limits shown in the following sections where local traffic laws permit a 28,000-lb. gross vehicle load.

These designs are based on the general line of reasoning outlined in the discussion following the sample designs, and theory developed in Chap. II:

Recommended Design 1. (See Fig. 108.)

Suitability.—Rural highway traffic range of 4,000 to 6,000 vehicles daily (10-hour count in summer season) in localities having a 28,000-lb. gross vehicle load limit.

Width.—20 ft. constructed ½ at a time.

Crown.—Circular arc radius 240 ft. edge 2⅛ in. below center line.

Concrete.—1:1½:3 mix with cement content not to exceed 1.9 and crushing strength 28-day age of from 3,000 to 4,000 lb. per square inch.

Transverse Joints.—¾-in. premolded asphalt spaced 33 ft., care being taken to insure vertical position of joint. Joints to be ½ in. deeper than pavement and cut off after completion of pavement. Concrete to be rounded with an edge radius ¼ in. on both sides of joint. Joints to be backed with 16-gage steel plates ½ in. less depth than pavement on grades of 4 per cent or more to insure vertical position. *No Dowels or grooves at joints.*

Depth of Concrete.—Based on Table 23, page 137.

	Outside Edge, Inches	Interior Areas, Inches
Ordinary soils	8¼	7¼
Gravel or macadam	7½	6½

Over freshly back-filled culvert trenches over 5 ft. wide increase depth and place bottom reinforcement to conform to culvert slab practice.

Reinforcement.—Combination of mesh and bar. Galvanized mesh to weight not less than 0.4 lb. per square foot with the main members having an effective area of not less than 0.11 sq. in. per foot width of mesh and spaced not over 4 in. c to c; the tie members to be spaced not over 12 in. c to c. Corner bars size and spacing based on formulæ, $S = \frac{2.4W}{d^2}$ with W = 14,000 lb. (see page 127). Percentage area of corner bar reinforcement approximately 0.3 of 1 per cent. Tie bars; arbitrary assumption as shown.

Quantities required per 100 *ft. of road for this design.*—

	New Grading	Resurfacing Jobs
Concrete, cubic yard	47.85	44.77
Mesh, square feet	2,100	2,100
Steel, pounds	860	860
Expansion joints, linear feet	60	60

Approximate cost (1922) *per square yard.*	New Grading	Resurfacing Jobs
Concrete	$2.70	$2.59
Mesh	0.28	0.28
Steel	0.10	0.10
Expansion joints	0.03	0.03
Total	$3.20	$3.00

A 9¼-in. depth of plain concrete which is equal in strength to this design costs approximately $3.40 per square yard for new grading conditions.

Recommended Design 2. (See Fig. 109.)

Suitability.—Rural highway traffic range of 1,500 to 4,000 vehicles daily (10-hour count in summer season) in localities having a 28,000-lb. gross vehicle load limit.

Width.—18 ft. constructed ½ at a time.

Crown.—Circular arc radius 200 ft. Edge 2 in. below center line.

Concrete.—1:1½:3 mix with cement content not to exceed 1.9 and crushing strength 28-day age of from 3,000 to 4,000 lb. per square inch.

Tranverse Joints.—Same as Design 1.

Depth of Concrete.—(Based on Table 23, page 137.)

	Outside Edge, Inches	Interior Areas, Inches
Ordinary soils	8½	7¾
Macadam or gravel	7¾	7

Over freshly back-filled culvert trenches over 5 ft. wide increase depth and use bottom reinforcement to conform to standard culvert slab practice.

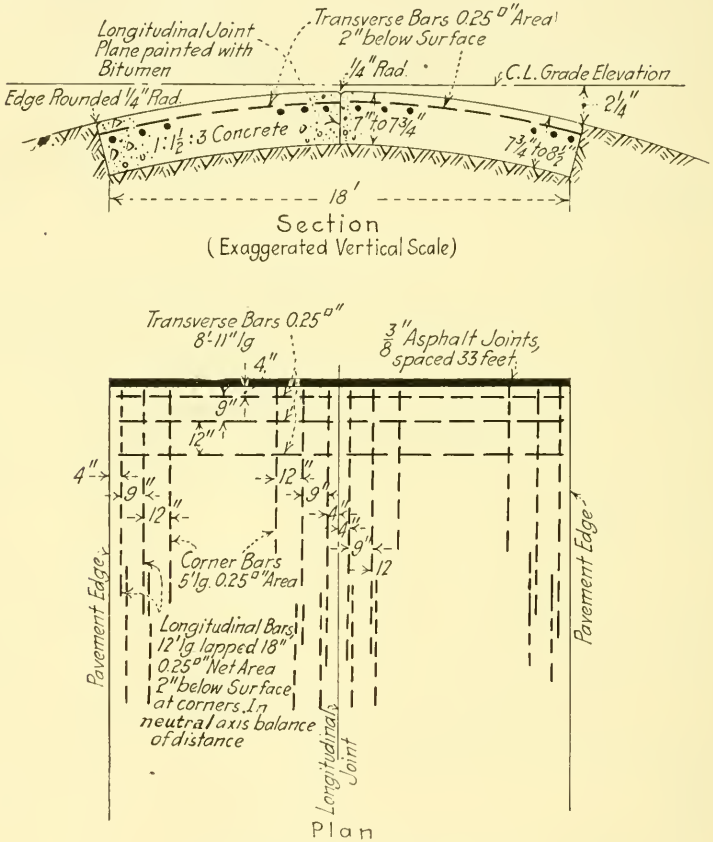


Fig. 109.—Recommended Design 2.

Reinforcement.—Bars only. Size and spacing of corner bars based on formula $S = \frac{2.4W}{d^2}$ with W = 14,000 lb. Percentage area of corner bar reinforcement approximately 0.25 of 1 per cent. Tie bars arbitrary assumption as shown.

Quantities per 100 ft. of road for this design.—

	New Grading	Resurfacing Jobs
Concrete, cubic yards	44.44	41.97
Steel, pounds	1,110	1,110
Expansion joints, linear feet	54	54

Approximate cost (1922) *per square yard.*

	New Grading	Resurfacing Jobs
Concrete	$2.83	$2.63
Steel	0.14	0.14
Expansion joints	0.03	0.03
Total	$3.00	$2.80

A plain concrete pavement of equal strength costs about $3.30 per square yard.

Recommended Design 3. (See Fig. 110.)

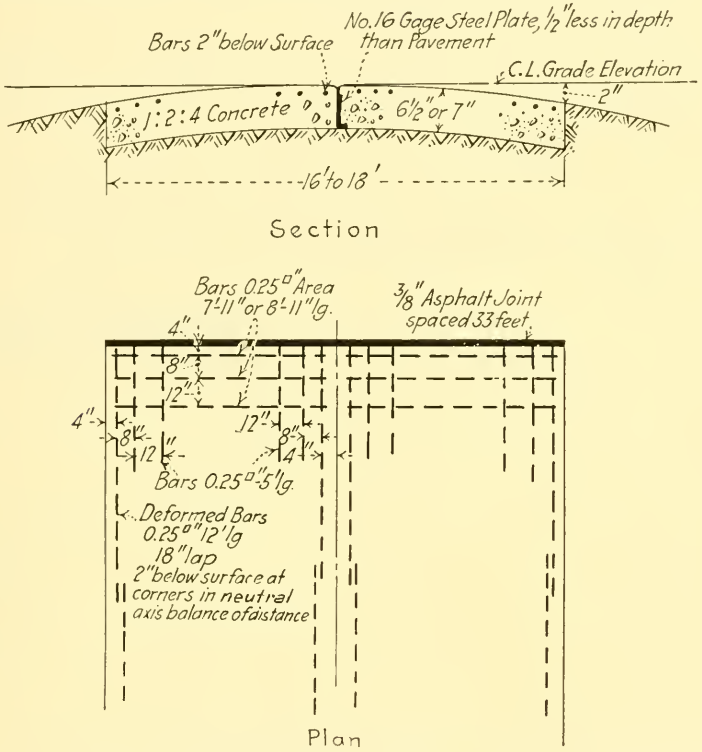

No. 16 Gage Steel Plate, ½" less in depth than Pavement
Bars 2" below Surface
C.L. Grade Elevation
2"
1:2:4 Concrete
6½" or 7"
16' to 18'
Section
Bars 0.25□" Area 7'-11" or 8'-11" lg.
⅜" Asphalt Joint spaced 33 feet
4"
8"
12"
Bars 0.25□"-5' lg.
Deformed Bars 0.25□" 12' lg 18" lap 2" below surface at corners in neutral axis balance of distance
Plan

Fig. 110.—Recommended Design 3.

Suitability.—Rural highway traffic of less than 1,500 daily. For these traffic conditions a concrete pavement is rarely justified from an engineering standpoint. Local demand, however, sometimes requires this type under these conditions and for the purposes of expediency it is often desirable to meet the demand. Under these conditions it is just as well to cut the first cost to a minimum and design the pavement with the idea of recapping with asphalt, etc., as soon as it shows the need. It should, however, be made strong enough so that an asphalt surface will raise its strength to that required for main road loads.

Width.—16 to 18 ft. recommended, constructed ½ at a time or if full width is constructed at once use submerged longitudinal steel joint.

Crown.—Circular arc radius 200 ft. Edge 2 in. below center line.

Concrete.—1:2:4 mix with cement content of not over 1.7 and 28-day crushing strength of 2,500 to 3,500 lb. per square inch.

Transverse Joints.—Same as Design 1.

6½ to 7-*in. average thickness of concrete* for construction on new grading ordinary loams and clays based on formula $d = \sqrt{\frac{1.5W}{S}}$ with $W = 12{,}000$ and $S = 360$ lb. For gravel soils or resurfacing on top of old macadam cut depth ½ in. below formula.

Reinforcement.—Corner bars based on formula $S = \frac{2.4W}{d^2}$. Percentage area approximately 0.4 of 1 per cent.

Single side tie bar

Quantities per 100 *ft. of* 16-*ft. road for this design.*—

	New Grading	Resurfacing Jobs
Concrete, cubic yards	34.6	32.1
Steel, pounds	820	820
Expansion, linear feet	48	48

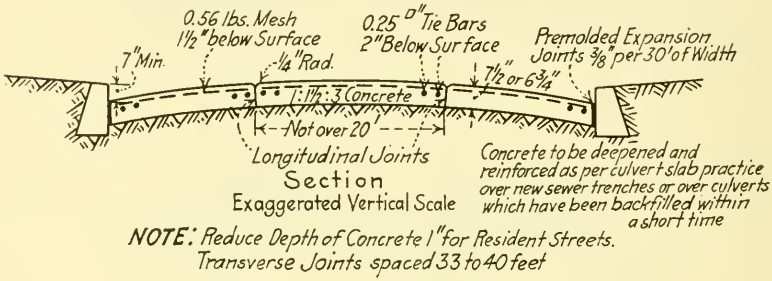


Fig. 111.—Recommended Design 4.

Approximate cost (1922) *for design No.* 3. *per square yard.*

	New Grading	Resurfacing Jobs
Concrete	$2.24	$2.08
Steel	0.12	0.12
Expansion	0.02	0.02
Longitudinal steel joints	0.04	0.04
	$2.42	$2.26

Design 4. (See Fig. 111.)

Suitability.—Village business street 28,000-lb. gross vehicle load limit.

Widths.—Any desired total width constructed in longitudinal strips of from 10- to 20-ft. width. Longitudinal joints painted with bitumen. Expansion along gutter line and at intervals of 33 to 40 ft. across road.

Crown.—Circular arc producing depth of edge below center line as shown on charts, page 315.

Curb.—7-in. high to permit future surfacing of asphaltic concrete or thin block.

Concrete.—1:1½:3 mix with cement content of not to exceed 2.0 and crushing strength 28-day age of 3,000 to 4,000 lb. per square inch.

Transverse Joints.—⅜ in. premoulded asphalt spaced 33 ft. Special care to keep straight and at right angles to curbs.

Depth of Concrete.—7½-in. uniform on loams and clays. 6¾-in. uniform on gravels and coarse sands.

Reinforcement.—Same as Design 1 except direction of main members of mesh which are at right angles to the direction shown in Design 1, where longitudinal joints are more than 12 ft. apart.

Mesh.—To weigh not less than 0.56 lb. per square foot and to have an effective area of 0.14 sq. in. per foot width. Corner bars 0.3 of 1 per cent of section area for 30 in. back from corners.

Summary of Current Practice.—The tabulation, page 258, gives a quick means of noting the essential features of current practice. This table was compiled by the Portland Cement Association in 1922. The typical sections following show standard sections of various design:

Materials.—The materials required are cement, gravel, stone or slag, sand or screenings, water, expansion joints, reinforcement and joint plates.

Cement.—The requirements of the Portland cement have been quite well standardized and the required quality can be obtained without much difficulty. All cement should, however, be tested and approved before use.

Cement specifications are given in Appendix A, page 550.

Cement tests are described in Appendix A, page 536.

Gravel and Broken Stone Aggregate.—The essential qualities of the coarse aggregate are that it be a clean, hard, well-graded size crushed rock or screened gravel product.

Where trap rock and the harder granites are available, the minimum hardness requirement for crushed stone is generally placed at French coefficient of 8 (5 per cent of wear). Where the limestones, hard sandstones and granite hardheads are the most feasible source of supply, the minimum French coefficient can be dropped to 7 (6 per cent of wear) with very good results. In exceptional cases a value as low as 6 (7 per cent of wear) has been used with moderate success but anything below 7 is risky for this type of pavement. The pavement is expensive and it is poor policy to use inferior materials which reduce the effectiveness of the result. The standard gravel abrasive test giving a 15 per cent wear is about equivalent to a 5 per cent wear of crushed stone Deval test (see Appendix A, page 505).

A graded size is desirable but it is not feasible to pay too much attention to this factor. Current practice favors a maximum size of $2\frac{1}{2}$ to $2\frac{3}{4}$ in. and a minimum of $\frac{1}{2}$ in. for a small percentage of the product. The $\frac{1}{2}$-in. size should not exceed 25 per cent of the total coarse aggregate which should be well graded between the $\frac{1}{2}$- and $2\frac{3}{4}$-in. limits.

Typical aggregate specifications are given in Appendix A, pages 537 and 545.

Typical tests of stone are described in Appendix A, page 505.

Slag Aggregate.—Crushed blast furnace slag has been given attention as a substitute for stone and gravel as in some localities its use materially cheapens the pavement. There has been considerable doubt as to the effect of slag in combination with cement. The slag concrete roads which have had service tests in conjunction with the laboratory extending over a considerable period indicate that a tough, strong concrete can be con-

COMPARISON OF STATE HIGHWAY DEPARTMENT SPECIFICATIONS FOR CONCRETE FOUNDATIONS FOR PAVEMENTS WITH SPECIFICATIONS FOR CONCRETE PAVEMENTS COMPILED BY PORTLAND CEMENT ASSOCIATION

January, 1923

State	Date of specifications	Thickness of base	Proportions		Time of mixing in minutes		Fine aggregate					Coarse aggregate				
							Are specifications for base as rigid as for pavement?	Minimum percentage of strength of Ottawa sand in 1:3 mortar		Maximum allowable percentage of clay or loam in sand		Are specifications as rigid for base as for pavement	Allowable per cent of wear for crushed stone		Maximum size in inches	
			Concrete base	Concrete pavement	Concrete base	Concrete pavement		Concrete base	Concrete pavement	Concrete base	Concrete pavement		Concrete base	Concrete pavement	Concrete base	Concrete pavement
Alabama	1920	..	1:9 1:3 :6	1:2 :3	1	1	No	75	100	5	3	No	...	5	3	2
Arizona	1922	..	1:3 :6	1:2 :3½	1	1	No	100	100	5	3	No	...	5	2½	2
Colorado	1922	..	1:3 :6	1:2 :3	1½	1½	Yes	100	100	3	3	No	5	4	2½	2
Delaware	1922	..	1:2½:5	1:2 :4	1	1½	Yes	100	100	3	3	Yes	3¼	3⅓	2¾	2¾
Florida	1919	..	1:3 :6	Top 1:2 :3	1	1	No	75	100	5	5	No	...	4	3	2
Georgia	1922	..	1:3 :6	1:2 :4	1	1	No	85	100	3	3	No	8	5	2¾	2¾
Illinois	1922	..	1:2 :3½	1:2 :3½	1	1	Yes	100	100	3	3	Yes	7	7	2½	2½
Indiana	1920	..	1:3 :5	1:2 :3	1	1	No	100	100	5	3	No	6	5	2½	2½
Kansas	1922	..	1:3 :5	1:2 :3½	1	1	No	80	100	5	3	No	...	7	3	2
Kentucky	1922	..	1:2½:5	1:2 :3½	1¼	1¼	Yes	100	100	3	3	Yes	6	6	2½	2½
Maryland	1922	6	1:3 :6	1:2 :4	1	1	No	75	100	5	3	No	5	4	2½	2¾
Michigan	1922	..	1:2 :4	1:1½:3	1	1	Yes	100	100	3	3	Yes	6	6	2½	2½
Missouri	1919	5	1:3 :5	1:2 :3	1	1	Yes	100	100	3	3	No	5	...	2	1½
Montana	1922	..	1:3 :6	1:2 :3	1	1	Yes	100	100	3	3	Yes	...	...	3	3
Nebraska	1922	..	1:3 :6	1:2 :3	1	1	Yes	100	100	3	3	No	6	4	2	2
New Jersey	1922	..	1:3 :5	1:1½:3	1¼	1½	Yes	100	100	4	4	Yes	3½	3½	3	3
North Carolina	1922	..	1:2½:5	1:1½:3	1½	1½	Yes	100	100	3	3	No	5	4	2¾	2¾
Ohio	1922	..	1:2½:5	1:1½:3	1	1	No	85	100	5	3	No	8	6	2½	2½
Oklahoma	1921	5	1:3 :6	1:2 :3	1	1½	No	75	100	5	3	No	6	6	2	2
Oregon	1922	..	1:3 :6	1:2 :3	1	1	No	90	100	4	2	No	5	4	3	3
Pennsylvania	1922	..	1:2½:5	1:2 :3	1¼	1¼	No	90	100	5	3	No	5	5	2¾	2¾
South Dakota	1920	..	1:3 :6	1:2 :3	1	1	No	75	100	5	3	No	...	5	3	2½
Utah	1922	..	1:3 :6	1:2 :3	1	1	No	90	100	5	3	Yes	5	5	3	2
Virginia	1920	..	1:3 :6	1:2 :4	1	1	No	85	100	5	3	No	8	5	2	2
West Virginia	1921	..	1:2½:5	1:2 :2½	1	1	No	75	100	3	3	Yes	6	6	3	3
Wisconsin	1922	5	1:2½:5	1:2 :4	1	1	Yes	100	100	3	3	Yes	6	6	2	2

NOTES.—Undated specifications listed with the date they were received from highway departments. Per cent wear listed is for crushed stone. Some specifications permit the use of pebbles or slag with lower per cent of wear, especially in the base. Specifications were not available for the states omitted.

structed of properly selected slag and that this concrete is not weakened by chemical action due to the slag aggregate. Road concrete constructed of slag, however, tends to pit on the surface due to a small percentage of pumice in the aggregate and this is unsightly at best. Slag concrete pavement serves the traffic quite satisfactorily and in certain instances it can be used to advantage but engineers as a rule prefer stone or hard gravel for most conditions of material supply. Slag aggregate is entirely satisfactory for concrete paving bases. Slag should weigh at least 1,800 lb. per cubic yard and have a test per cent of wear of not exceeding 12 per cent (Standard Slag Abrasion Test).

Sand.—The sand used should be a hard, clean, well-graded sand free from organic impurities and containing only a small percentage of loam or silt. A hard, sharp, graded sand which does not pulverize under rolling pressure or water slack is essential.

The sizings usually specified are as follows. (Percentages are by dry weight):

	Per Cent
100 passing ¼-in. sieve	
20 minus passing No. 50 sieve	
6 minus passing No. 100 sieve	
5 minus loam and silt.	

Sand and cement mixed in the same proportion required for pavement must develop at least as much strength as standard Ottawa sand and cement mixed in the same proportions.

In exceptional cases rock crusher dust can be substituted for a part or whole of the natural sand aggregate but under the usual conditions of material supply this expedient should be used with caution (see Specifications, Appendix A and Sand Tests, Appendix A).

Water.—Water shall be free from silt and organic matter and shall not show a strong alkaline or acid reaction. (See Appendix A for tests.)

Expansion Joint—The premoulded type is the most practicable form for good work; the required properties and tests are given in Appendix A.

Joint Plates.—Straight steel or corrugated steel plates No. 14 or 16 U. S. gage with flange on the bottom punched for spiking to the grade are as good a form as can be used. Sixteen gage is thin enough (see Figs. 114 and 115). It is believed that the straight plate is superior to the grooved or corrugated form which tends to increase the liability of spauling.

Factors of Design.—The main factors of design are richness of mix; reinforcement and joint details. Manipulation methods covering time of mix, care in curing, joints, etc., are discussed under Specifications, Inspection Details and Appendix F.

Richness of Mix.—Richness of mix affects beam strength, resistance of the pavement surface to abrasion and the imperviousness of the surface, seepage and disintegration due to frost action. Road concretes in ordinary use (1922) range from 1:2:4 to 1:1½:3 mix with cement contents of from 1.6 to 2.1 bbl. per cubic yard of concrete.

While beam strength is slightly increased by added richness of mix, this factor has very little weight in the final decision as there is no well-defined advantage of greater unit strength and less depth. The decision in regard to mix rests on its effect on abrasion and the porosity of the concrete. That is, richness above 1:2½:5 is entirely dependent on the production of a longer surface life before the pavement needs recapping. On this basis of reasoning, it is certainly not desirable to increase the cost over that required for 1:2½:5 mix by more than $0.10 to $0.15 per square yard for each additional year of surface life. A mix of 1:2½:5 (1.25 bbl. of cement per cubic yard) taking traffic directly is not satisfactory or economical under even moderate traffic and even where such a surface is given a light protective coat of oil and screenings, it rarely lasts over 3 to 5 years before a surface of asphaltic concrete or standard block is necessary. A considerable mileage of 1:2:4 concrete pavements (1.6 to 1.7 bbl. of cement per cubic yard) have demonstrated their ability to withstand moderate traffic up to 3,000 rubber tired vehicles daily (10-hour count in summer) for a reasonable term of years (6 to 12) before recapping is desirable. The increased cost of this mix over and above the 1:2½:5 mix is most certainly justified as it amounts to approximately 0.1 bbl. per square yard or in money about $0.30 per square yard initial cost which probably adds at least 5 years to its surface life. In actual practice under the usual inspection and batching procedure, considerable variation of mix will occur which produces occasional areas of concrete which are not a true 1:2:4 mix. There have been enough failures of small areas apparently due to porosity using this mix to warrant a slight increase in richness to offset construction imperfections on even moderate traffic roads and on heavy traffic roads a 1:1½:3 mix is apparently justified to increase density to withstand traffic pounding. The average life of such pavements cannot yet be set and will vary greatly due to different traffic and excellence of construction but they seem to be about as an expensive a mix as is desirable. A cement content of over 1.9 bbl. per cubic yard is of doubtful value and seems a waste of money except possibly on village pavements. This is not a needless caution as the cement factor has been steadily rising and while from the standpoint of the material industries, it is desirable to sell all the cement possible, it is poor engineering to use a needless amount. The latest expedient is to call a sack of cement 0.95 cu. ft. in place of 1.0 cu. ft., which raises the cement factor about 5 per cent.

Tentative conclusions in regard to richness of mix may be expressed as follows:

For light and moderate traffic roads up to 3,000 vehicles daily, a mix of approximate 1 : 1¾ : 3½ with an average cement content of not to exceed 1.7 bbl. per cubic yard ought to give satisfactory results provided the batching scheme prevents individual batches varying more than 7 per cent from the average. (This is a reasonable limit of variation under modern specifications.) This mix should show a 28-day age compressive strength of from 2,500 to 3,500 lb. per square inch.

For the heavier traffic roads (3,000 to 6,000 vehicles daily) a mix of approximately 1:1½: 3 with a cement content of not to exceed 1.9 ought to give satisfactory results and appears to be economically justified. This mix should show tests of 3,000 to 4,000 lb. at 28 days.

The following table shows Abram's proportions for 3,000-lb. concrete; it is an excellent general guide but considering the wide range in aggregate sizes as delivered, it is impracticable to cut the proportioning too fine. For explanation of fineness modulus method of proportioning mix, see Appendix F.

ABRAMS' TABLE OF PROPORTIONS AND QUANTITIES FOR 1 CU. YD. OF CONCRETE

Based upon laboratory investigations, using approved materials, compressive strength, 28 days, with workable plasticity, 6- by 12-in. cylinders, 3,000 lb. per square inch.

Sizes		Fine aggregates, screen per inch														
Coarse aggregate, inches	Cement in barrels aggregates in cubic yards	0–28			0–14			0–8			0–4			0–⅜ in.		
		Cement	Fine	Coarse	Cement	Fine	Coarse	Cement	Fine	Coarse	Cement	Fine	Coarse	Cement	Fine	Coarse
No. 4 screen to ¾	Proportions	**1.0**	**1.3**	**2.4**	**1.0**	**1.6**	**2.4**	**1.0**	**1.8**	**2.3**	**1.0**	**2.0**	**2.3**	**1.0**	**2.7**	**1.5**
	Quantities	1.96	0.37	0.69	1.85	0.44	0.66	1.82	0.48	0.62	1.75	0.52	0.59	1.79	0.72	0.40
No. 4 screen to 1	Proportions	**1.0**	**1.3**	**2.7**	**1.0**	**1.6**	**2.6**	**1.0**	**1.8**	**2.6**	**1.0**	**2.0**	**2.5**	**1.0**	**2.6**	**1.8**
	Quantities	1.90	0.36	0.76	1.77	0.42	0.68	1.72	0.46	0.66	1.67	0.50	0.62	1.72	0.66	0.46
No. 4 screen to 1½	Proportions	**1.0**	**1.2**	**3.1**	**1.0**	**1.6**	**3.2**	**1.0**	**1.7**	**3.1**	**1.0**	**2.0**	**3.0**	**1.0**	**2.4**	**2.4**
	Quantities	1.82	0.32	0.84	1.68	0.40	0.79	1.63	0.41	0.75	1.61	0.47	0.72	1.62	0.57	0.57
No. 4 screen to 2	Proportions	**1.0**	**1.2**	**3.5**	**1.0**	**1.5**	**3.5**	**1.0**	**1.6**	**3.7**	**1.0**	**1.9**	**3.6**	**1.0**	**2.2**	**3.1**
	Quantities	1.75	0.31	0.90	1.63	0.36	0.85	1.55	0.36	0.85	1.52	0.43	0.81	1.53	0.50	0.70
No. 4 screen to 2½	Proportions	**1.0**	**1.1**	**3.8**	**1.0**	**1.4**	**3.9**	**1.0**	**1.6**	**4.0**	**1.0**	**1.8**	**4.0**	**1.0**	**2.1**	**3.5**
	Quantities	1.72	0.28	0.97	1.58	0.33	0.91	1.51	0.35	0.89	1.49	0.40	0.88	1.50	0.46	0.78
No. 4 screen to 3	Proportions	**1.0**	**1.1**	**3.9**	**1.0**	**1.4**	**4.1**	**1.0**	**1.5**	**4.1**	**1.0**	**1.7**	**4.1**	**1.0**	**2.0**	**3.7**
	Quantities	1.69	0.28	0.97	1.58	0.33	0.97	1.49	0.33	0.90	1.49	0.37	0.90	1.49	0.44	0.81
⅜ to ¾	Proportions	**1.0**	**1.3**	**2.3**	**1.0**	**1.7**	**2.3**	**1.0**	**1.9**	**2.3**	**1.0**	**2.2**	**2.2**	**1.0**	**2.8**	**1.4**
	Quantities	1.96	0.37	0.67	1.85	0.46	0.63	1.82	0.51	0.62	1.75	0.57	0.57	1.79	0.75	0.37
⅜ to 1	Proportions	**1.0**	**1.3**	**2.6**	**1.0**	**1.7**	**2.6**	**1.0**	**1.9**	**2.5**	**1.0**	**2.2**	**2.4**	**1.0**	**2.7**	**1.7**
	Quantities	1.90	0.36	0.74	1.77	0.44	0.68	1.72	0.48	0.64	1.67	0.54	0.59	1.72	0.68	0.43
⅜ to 1½	Proportions	**1.0**	**1.3**	**3.0**	**1.0**	**1.7**	**3.0**	**1.0**	**1.9**	**3.0**	**1.0**	**2.1**	**2.9**	**1.0**	**2.6**	**2.2**
	Quantities	1.82	0.35	0.80	1.68	0.43	0.75	1.63	0.46	0.73	1.61	0.50	0.68	1.62	0.63	0.53

ABRAMS' TABLE OF PROPORTIONS AND QUANTITIES FOR 1 CU. YD. OF CONCRETE—*Continued*

Sizes		Fine aggregates, screen per inch														
Coarse aggregates, inches	Cement in barrels aggregates in cubic yards	0–28			0–14			0–8			0–4			0–3/8 in.		
		Cement	Fine	Coarse	Cement	Fine	Coarse	Cement	Fine	Coarse	Cement	Fine	Coarse	Cement	Fine	Coarse
3/8 to 2	Proportions	**1.0**	**1.3**	**3.3**	**1.0**	**1.7**	**3.4**	**1.0**	**1.8**	**3.5**	**1.0**	**2.0**	**3.4**	**1.0**	**2.4**	**2.9**
	Quantities	1.75	0.34	0.86	1.63	0.41	0.83	1.55	0.42	0.80	1.52	0.45	0.77	1.53	0.62	0.66
3/8 to 2½	Proportions	**1.0**	**1.3**	**3.7**	**1.0**	**1.6**	**3.7**	**1.0**	**1.7**	**3.9**	**1.0**	**2.0**	**3.8**	**1.0**	**2.3**	**3.3**
	Quantities	1.72	0.33	0.95	1.58	0.37	0.87	1.51	0.37	0.87	1.49	0.44	0.84	1.50	0.51	0.74
3/8 to 3	Proportions	**1.0**	**1.2**	**3.8**	**1.0**	**1.6**	**3.9**	**1.0**	**1.7**	**4.0**	**1.0**	**1.9**	**4.0**	**1.0**	**2.2**	**3.5**
	Quantities	1.68	0.30	0.95	1.58	0.37	0.91	1.49	0.37	0.88	1.49	0.42	0.88	1.49	0.48	0.77
½ to ¾	Proportions	**1.0**	**1.5**	**2.3**	**1.0**	**1.9**	**2.2**	**1.0**	**2.1**	**2.2**	**1.0**	**2.3**	**2.1**	**1.0**	**2.8**	**1.3**
	Quantities	1.96	0.44	0.67	1.85	0.52	0.61	1.82	0.56	0.59	1.75	0.59	0.54	1.79	0.75	0.34
½ to 1	Proportions	**1.0**	**1.5**	**2.5**	**1.0**	**1.9**	**2.5**	**1.0**	**2.1**	**2.4**	**1.0**	**2.3**	**2.4**	**1.0**	**2.8**	**1.6**
	Quantities	1.90	0.42	0.70	1.77	0.50	0.66	1.72	0.53	0.61	1.67	0.57	0.59	1.72	0.72	0.41
½ to 1½	Proportions	**1.0**	**1.4**	**2.8**	**1.0**	**1.9**	**2.9**	**1.0**	**2.1**	**2.9**	**1.0**	**2.2**	**2.8**	**1.0**	**2.7**	**2.1**
	Quantities	1.82	0.37	0.75	1.68	0.47	0.73	1.63	0.51	0.69	1.61	0.52	0.66	1.62	0.65	0.51
½ to 2	Proportions	**1.0**	**1.4**	**3.3**	**1.0**	**1.9**	**3.3**	**1.0**	**2.0**	**3.4**	**1.0**	**2.2**	**3.3**	**1.0**	**2.7**	**2.7**
	Quantities	1.75	0.36	0.86	1.63	0.46	0.79	1.55	0.46	0.78	1.52	0.50	0.74	1.53	0.62	0.62
½ to 2½	Proportions	**1.0**	**1.4**	**3.6**	**1.0**	**1.8**	**3.6**	**1.0**	**1.9**	**3.7**	**1.0**	**2.1**	**3.7**	**1.0**	**2.6**	**3.1**
	Quantities	1.72	0.35	0.91	1.58	0.43	0.85	1.51	0.42	0.83	1.49	0.46	0.81	1.50	0.57	0.69
½ to 3	Proportions	**1.0**	**1.3**	**3.7**	**1.0**	**1.8**	**3.8**	**1.0**	**1.8**	**3.9**	**1.0**	**2.1**	**4.0**	**1.0**	**2.4**	**3.3**
	Quantities	1.68	0.33	0.92	1.58	0.42	0.89	1.49	0.40	0.86	1.49	0.46	0.88	1.49	0.53	0.63
¾ to 1	Proportions	**1.0**	**1.7**	**2.4**	**1.0**	**2.1**	**2.4**	**1.0**	**2.4**	**2.1**	**1.0**	**2.6**	**2.2**	**1.0**	**3.1**	**1.5**
	Quantities	1.90	0.48	0.68	1.77	0.55	0.63	1.72	0.61	0.53	1.67	0.64	0.55	1.72	0.79	0.39
¾ to 1½	Proportions	**1.0**	**1.7**	**2.7**	**1.0**	**2.0**	**2.8**	**1.0**	**2.3**	**2.7**	**1.0**	**2.5**	**2.7**	**1.0**	**3.0**	**2.0**
	Quantities	1.82	0.46	0.73	1.79	0.50	0.70	1.63	0.55	0.65	1.61	0.59	0.64	1.62	0.73	0.48
¾ to 2	Proportions	**1.0**	**1.7**	**3.1**	**1.0**	**2.0**	**3.1**	**1.0**	**2.3**	**3.1**	**1.0**	**2.5**	**3.0**	**1.0**	**3.0**	**2.4**
	Quantities	1.75	0.44	0.80	1.63	0.48	0.75	1.55	0.53	0.72	1.52	0.56	0.67	1.53	0.68	0.55
¾ to 2½	Proportions	**1.0**	**1.7**	**3.3**	**1.0**	**2.0**	**3.5**	**1.0**	**2.3**	**3.4**	**1.0**	**2.4**	**3.4**	**1.0**	**2.9**	**2.8**
	Quantities	1.72	0.43	0.84	1.63	0.47	0.83	1.51	0.52	0.76	1.49	0.53	0.75	1.50	0.64	0.62
¾ to 3	Proportions	**1.0**	**1.7**	**3.5**	**1.0**	**2.0**	**3.7**	**1.0**	**2.3**	**3.7**	**1.0**	**2.4**	**3.6**	**1.0**	**2.8**	**3.1**
	Quantities	1.68	0.43	0.88	1.58	0.47	0.87	1.49	0.51	0.81	1.49	0.53	0.79	1.49	0.62	0.68
1 to 1½	Proportions	**1.0**	**1.7**	**2.8**	**1.0**	**2.0**	**2.9**	**1.0**	**2.3**	**2.7**	**1.0**	**2.6**	**2.6**	**1.0**	**3.1**	**2.0**
	Quantities	1.82	0.46	0.75	1.68	0.50	0.73	1.63	0.55	0.65	1.61	0.62	0.62	1.62	0.75	0.48
1 to 2	Proportions	**1.0**	**1.5**	**3.2**	**1.0**	**1.9**	**3.5**	**1.0**	**2.2**	**3.3**	**1.0**	**2.4**	**3.3**	**1.0**	**3.0**	**2.6**
	Quantities	1.75	0.39	0.83	1.63	0.46	0.85	1.58	0.51	0.76	1.52	0.54	0.74	1.53	0.68	0.59
1 to 2½	Proportions	**1.0**	**1.4**	**3.4**	**1.0**	**1.9**	**3.8**	**1.0**	**2.0**	**3.7**	**1.0**	**2.3**	**3.7**	**1.0**	**2.7**	**3.1**
	Quantities	1.72	0.35	0.86	1.58	0.45	0.89	1.51	0.44	0.83	1.49	0.51	0.81	1.50	0.59	0.69
1 to 3	Proportions	**1.0**	**1.3**	**3.6**	**1.0**	**1.8**	**4.0**	**1.0**	**2.0**	**3.9**	**1.0**	**2.2**	**3.9**	**1.0**	**2.7**	**3.3**
	Quantities	1.67	0.33	0.90	1.58	0.42	0.94	1.49	0.44	0.86	1.49	0.48	0.86	1.49	0.59	0.73

AMOUNTS OF MATERIAL REQUIRED

Amount of Water.—The amount of water required will vary with the natural dampness of the loose aggregate, its sizing and the cement content of the mix. For the usual 1 : 1½ : 3 concrete having a good workable consistency the use of from 30 to 40 gal. per cubic yard is about right. Either excessively dry or sloppy concrete is undesirable. Some specifications describe slump tests to determine consistency (see page 264). Such clauses are undoubtedly desirable in case of dispute but for ordinary construction operations visual inspection is sufficient. The concrete should be plastic. That is it should not be so wet that the mortar and stone separate when dumped or so wet that after rolling and finishing free water runs off the surface and drips off the forms. It is desirable for the mortar to flow slightly as this produces a denser concrete with the usual amount of manipulation obtained under ordinary working conditions. Theoretically fairly dry concrete is stronger than the plastic mix but if a mix is so dry that it requires unusual care in spreading,

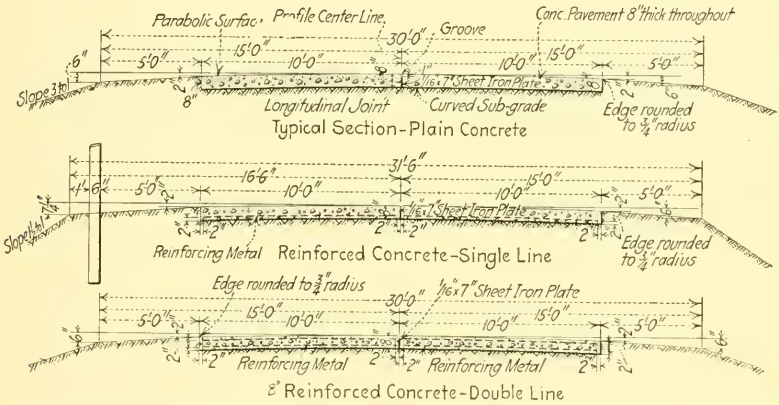


FIG. 112.—State of New Jersey (1922) Standard plain and reinforced concrete pavements.

tamping and spading the actual result day after day is not as satisfactory as where the plastic mix is used.

Sprinkling subgrade takes from ½ gal. per square yard to 1½ gal. for dry sand per square yard of pavement.

Curing concrete takes from 10 to 30 gal. per square yard if properly done depending on weather conditions and time of year. For the effect of curing on strength, see Appendix F.

The total amount of water all purposes will range from 20 to 40 gal. per square yard ordinary depths of concrete or from 70 to 150 gal. per cubic yard of concrete.

Slump Test Values.—For purposes of defining the limits of allowable consistency in the specifications the Slump Test Definition is probably desirable. The standard test is described in Appendix A, page 541. According to Prof. Abrams of Lewis Institute the following range will produce satisfactory consistency.

Machine finishing methods	1- to 2-in. slump
Hand finishing methods	3- to 4-in. slump

Reinforcement and Joints.—The use of steel in concrete pavements is a comparatively recent development. Figures 112 to 116 show the different methods in use at present (1922). The wide variation in type, location and function of the steel as used indicates conclusively that there is no certain knowledge as to the exact value of reinforcement in pavement design.

It is conceded that the use of some steel is practically and economically justified for the purposes of equalizing construction imperfections in the

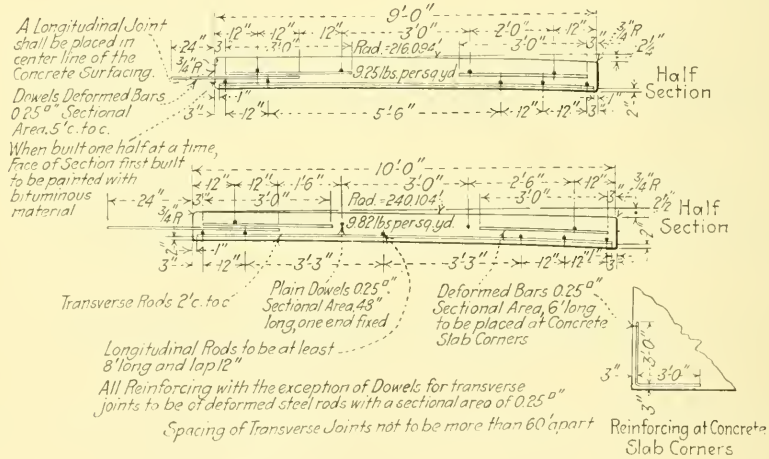
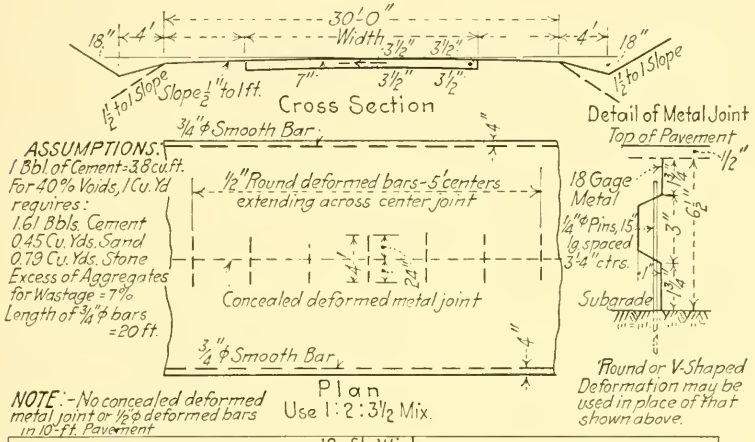

A Longitudinal Joint shall be placed in center line of the Concrete Surfacing.
Dowels Deformed Bars 0.25 sq in Sectional Area, 5'c. to c.
When built one half at a time, face of Section first built to be painted with bituminous material
9'-0"
Rod = 216.0 sq in
9.25 lbs per sq yd
Half Section
10'-0"
Rod = 240.104 sq in
9.82 lbs per sq yd
Half Section
Transverse Rods 2'c. to c.
Plain Dowels 0.25 sq in Sectional Area, 48" long, one end fixed
Deformed Bars 0.25 sq in Sectional Area, 6' long to be placed at Concrete Slab Corners
Longitudinal Rods to be at least 8' long and lap 12"
All Reinforcing with the exception of Dowels for transverse joints to be of deformed steel rods with a sectional area of 0.25 sq in
Spacing of Transverse Joints not to be more than 60' apart
Reinforcing at Concrete Slab Corners

FIG. 113.—Massachusetts concrete road section (1922).

concrete, to prevent interior cracks from spreading apart, to strengthen corners for cantilever load stresses and shear, and possibly to help keep adjacent slabs at the same elevation and distribute wheel loads across joints. There is, however, considerable doubt as to the wisdom of the use of the amount of steel shown in some recent designs. Central areas of slabs are indeterminate in design as there is no way of telling how they are stressed under the fluctuating conditions of traffic loads and subgrade support. It is uneconomical to attempt to increase the slab strength of central areas by the use of steel as a true reinforcement.

The design of depth for a pavement where reinforcement is used differs from that of plain concrete. The assumptions for the design of plain concrete slabs are quite rational and definite, namely: The greatest stress is produced by a live load at the extreme corner of a slab; if the slab is designed of uniform strength throughout and made strong enough to resist corner failure, the pavement should serve well even though



	Cement bbls.	Fine Aggr. Cu. Yds.	Coarse Aggr. Cu. Yds.	Concrete Cu. Yds	Deformed Metal Joint lbs	¼" Round Pins lbs.	¾" Round Smooth Bar lbs.	½" Deformed Bar, lbs.
10-ft. Wide								
100'	34.78	10.40	18.26	21.60	None	None	333.33	None
1 Mi.	1836.38	549.12	964.13	1140.69	"	"	17599.82	"
1 Sq. Yd.	.313	.094	.164	.194	"	"	3.00	"
16-ft. Wide								
100'	55.65	16.64	29.22	34.57	132.94	6.26	333.33	53.44
1 Mi.	2938.32	878.59	1542.82	1825.30	7019.23	330.53	17599.82	2821.63
1 Sq. Yd.	.313	.094	.164	.194	.748	.035	1.875	.301
18-ft. Wide								
100'	62.61	18.72	32.87	38.88	132.94	6.26	333.33	53.44
1 Mi.	3305.81	988.42	1735.54	2052.86	7019.23	330.53	17599.82	2821.63
1 Sq. Yd.	.313	.094	.164	.194	.665	.031	1.667	.267
20-ft. Wide								
100'	69.57	20.81	36.52	43.20	132.94	6.26	333.33	53.44
1 Mi.	3673.30	1098.77	1928.26	2280.96	7019.23	330.53	17599.82	2821.63
1 Sq. Yd.	.313	.094	.164	.194	.598	.028	1.50	.240

FIG. 114.—Illinois concrete pavements (1922).

internal cracks occur and the elimination of such cracks is not of much importance except on the ground of appearance. These assumptions, however, require the use of a needless amount of concrete in internal areas where cracks do not develop. If internal cracks can be eliminated or reduced to an infrequent occurrence, it is evident that the use of steel at corners tends to produce a slab of more uniform resistance and makes it possible to reduce the required thickness of concrete. From an economic standpoint, it is therefore desirable to use some steel for the purpose

of increasing corner strength. The rational and sure use of steel at corners with thinner concrete depends on the control of internal cracking.

The successful use of steel requires the subdivision of the pavement into slabs of such size that their integrity can usually be preserved under

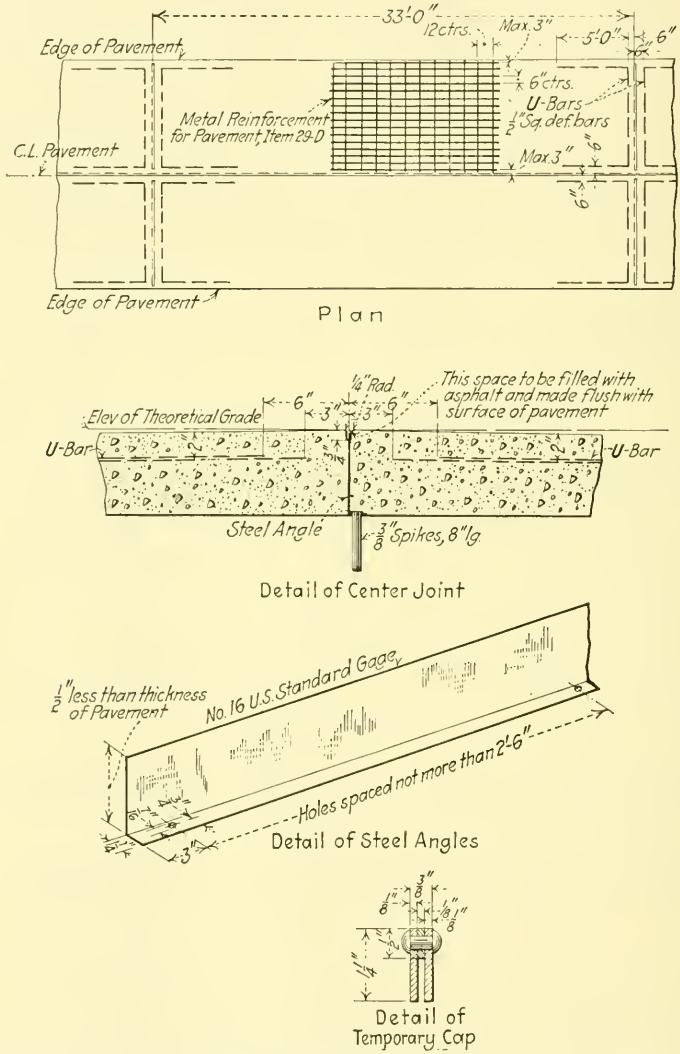


FIG. 115.—New York State standard concrete section (1922). Concrete 7-in. thick for this type of reinforcement.

the action of traffic and frost. It is undesirable to reduce the size of slab below the maximum feasible size as additional joints introduce additional corners which are points of weakness and more wear occurs at

joints from spalling, etc. A small sized slab also tends to rock under eccentric loading.

The decision in regard to spacing of contraction, expansion and longitudinal joints should reduce internal cracking to negligible frequency. If transverse joints are provided at intervals of about 30 to 35 ft. and longitudinal joints are provided for each 8 to 10 ft. of pavement width, we know from experience that we are providing for controlled cracks which correspond with the natural cracking tendency of concrete under frost and traffic action. That is, the adoption of this system of joints gener-

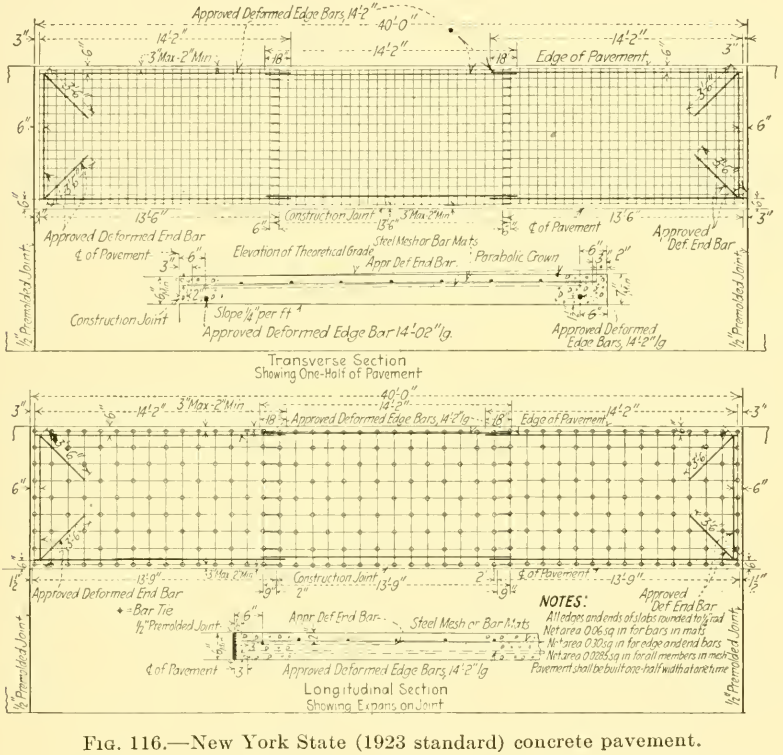

Approved Deformed Edge Bars, 14'-2"
40'-0"
Edge of Pavement
Approved Deformed End Bar
℄ of Pavement
Steel Mesh or Bar Mats
Parabolic Crown
Approved Def. End Bar
Construction Joint
Slope ¼" per ft
Approved Deformed Edge Bar 14'-02" lg.
Approved Deformed Edge Bars, 14'-2" lg
½" Premolded Joint
Transverse Section
Showing One-Half of Pavement
Bar Tie
Anner Def. End Bar
NOTES:
All edges and ends of slabs rounded to ¼" rad
Net area 0.06 sq in for bars in mats
Net area 0.30 sq in for edge and end bars
Net area 0.0285 sq in for all members in mesh
Pavement shall be built one-half width at a time
Longitudinal Section
Showing Expansion Joint

Fig. 116.—New York State (1923 standard) concrete pavement.

ally eliminates frequent internal cracks provided the pavement has sufficient depth of handle traffic loads. This system of subdivided slabs with depths of 7 to 8 in. of concrete will practically eliminate internal cracks and if the corners are reinforced enough to prevent corner cracks for these depths we have a fairly rational design. This can be done by corner reinforcement (see Chap. II). It is undesirable to reduce the thickness below the depths shown in Table 23. The proper use of corner reinforcement and tie bars around the slabs apparently justifies a reduction in average thickness of the concrete of about 1 to 1½ in. under that required for a plain concrete slab.

This saving justifies a maximum expenditure of about $0.045 per square foot (1922 costs) for steel or about 1.0 to 1.5 lb. of steel per square foot.[1] This amount is not often necessary or advisable. The use of approximately 0.5 to 0.8 lb. per square foot apparently gives a rational and economical result for most cases and this amount is most certainly a good investment considering pavement cost.

The use of steel in pavements may be briefly summarized as follows. Figures 108 to 111 show typical systems of reinforcement which appear logical.

Mesh and Bar Types of Reinforcement.—The mesh type having small unit members and close spacing is probably more effective than bars for equalizing construction imperfections, temperature and moisture stresses. It can be placed closer to the surface of the pavement with less probability of chipping of the concrete than bar reinforcement. Theoretically, it has very little effect as a true tension reinforcement but its use seems beneficial in reducing longitudinal cracks in wide slabs. It is particularly useful on wide street pavements where it seems undesirable on account of appearance to divide the pavement into narrow strips.

The bar type is better to hold adjacent slabs in contact after a crack occurs and bars can be more scientifically arranged to give the most effective result where an effort is made to use steel as a true tension reinforcement. Bars, however, must be placed farther below the surface (at least 2 in.) and they are not very effective as a true tension reinforcement where the pavement depth is less than 7 to 8 in. Bars can be most effectively used as corner reinforcement and as ties around the outer edges of the slabs. Where used as ties, they are effective for any depth that may be adopted.

Where the bars are used, they are generally assembled into mats and tied together to insure proper spacing and elevation in the concrete. Theoretically, this may be desirable but it requires additional isolated tie bars which have very little practical value. Personally, the author has never experienced any difficulty in placing bars by hand sufficiently close to their proper location provided the reinforcement is all in the same horizontal plane. The man placing the steel must be intelligent but his wage is more than offset by the saving in the labor of manufacturing the mats and in the saving of unnecessary tie bars.

The typical recommended sections Figs. 108 to 111 assume that the bars are placed by hand and are not wired. If it is desired to use the mat form, add tie bars at the longitudinal laps.

Corner Reinforcement.—Figure 42, page 114, shows graphically the effect of different percentages of steel on modulus of rupture; as discussed in Chap. II, it is probably not desirable to raise the design tension value above 65 per cent of the modulus of rupture for 28-day concrete.

[1] Mesh is an expensive form of reinforcement and should be used only on the heaviest type of pavement.

There are two formulae that can be considered in approximating the amount of reinforcement in corners. These formulae given in Chap. II, page 127, are as follows.

(1) $d = \sqrt{\frac{2.6W}{S}}$ $\qquad S = \frac{2.6W}{d^2}$

(2) $d = \sqrt{\frac{2W}{S}}$ $\qquad S = \frac{2W}{d^2}$

Formula 1 is the one adopted for plain concrete and assumes approximately 85 per cent of the wheel load carried by the corner. Number 2 assumes approximately 66 per cent of the wheel load carried by the corner. Formula 2 assumes the use of dowelled or grooved joints to help transmit the load across the joint. Formula 1 is on the safe side and as there is considerable doubt as to the practical effectiveness and desirability of dowelled joints it seems the more rational formula to use. For an 8-in. depth of 1:1 ½:3 concrete pavement on a main road in states having a statuatory limitation of 28,000-lb. gross vehicle load, the design wheel load plus impact is approximately 14,000 lb. and the value of S becomes

$$S = \frac{2.6\ (14{,}000)}{8^2} = 580 \text{ lb.}$$

A design tension value of 580 lb. requires at least 0.25 to 0.3 to 1 per cent reinforcement. The corner reinforcement shown in Fig. 108 is based on this assumption.

In a similar manner the following table is constructed. It is merely intended as a rough guide as the final decision rests on cut and try methods under actual traffic tests.

TABLE 29.—APPROXIMATE PERCENTAGE OF CORNER REINFORCEMENT

Depth of pavement, inches	Design wheel load (W) in pounds including impact allowance		
	8,000	14,000	20,000
6	0.3	Not suitable	Not suitable
7	0.0	0.4	Not suitable
8	0.0	0.25	0.5
9	0.0	0.0	0.35

TABLE 29A.—AREA OF STEEL IN SQUARE INCHES PER FOOT WIDTH OF SLAB (CORNER REINFORCEMENT)

Depth of pavement, inches	Design wheel load (W)		
	8,000	14,000	20,000
6	0.22	....	....
7	....	0.34	....
8	....	0.24	0.48
9	....	....	0.38

Most corner cracks occur at a distance of less than $2\frac{1}{2}$ ft. from the corner so that if corner reinforcement with the effective area given in these tables is provided for a distance of 2.5 ft. back from the corner, it is apparently a safe design. The recommended reinforcement layout of Fig. 108 is based on this assumption. A convenient size for corner reinforcement bars is $\frac{3}{8}$ or $\frac{1}{2}$ in.

Side Bars.—The use of some kind of a tie around the outer edges of the slabs is quite uniformly approved. Bars are effective in reducing spread of cracks which may develop. They increase the distribution of load across internal cracks by holding the parts in close contact and by dowel action. They should be strong enough to resist wheel load shear after the crack forms. They have practically no effect in increasing strength or in the prevention of the formation of cracks. Convenient sizes in general use are $\frac{1}{2}$- or $\frac{5}{8}$-in. bars (see Figs. 113, 114 and 118).

Dowels.—The advocates of the use of dowel-pin connections between adjacent slabs believe that such construction (see Fig. 113, page 264) keeps adjacent slabs at the same elevation and reduces the load carried by the slab corner. The sizes and spacing in ordinary use are shown in Fig. 114; the dowels are coated with bitumen or wrapped in paper or encased in pipe to permit movement at transverse joints. There is comparatively little trouble in the matter of equal level of adjacent slabs where the joints are smooth and vertical (see Fig. 131). The few cases which occur due to defective construction can be easily remedied. Personally, the author does not favor the idea of attempting to produce a 50 per cent distribution across construction transverse joints by means of dowel connections.[1] It is doubtful if pin or groove joints can be constructed which permit contraction and expansion and yet are still very effective in permanently transmitting load. It is believed that it is a better general principle of design to make the corners self-supporting by means of corner reinforcement, the action of which is reasonably sure.

The recommended designs Figs. 108 to 111 are based on this principle of design.

Joint Details.—It is desirable to reduce the number of joints to a minimum as they are generally the weak points in construction; they also tend to spall due to rub and traffic pounding. Also enough joints must be used to permit a rational use of steel. Less spall, however, occurs at well-defined joints with rounded edges and a complete smooth separation of adjacent blocks than at natural contraction cracks or where the submerged type of joint is used.

The treatment of expansion and contraction is the source of very wide disagreement among engineers.

[1] Tie bars at internal cracks are effective in producing distribution across such cracks as no expansion or contraction need be provided at these points where the road is constricted with transverse joints every 33 ft.

Expansion.—Some very excellent practice ignores expansion on the ground that the stress produced is well under the working stress of concrete in compression and that it is cheaper to repair infrequent blow-ups due to expansion than to spend the necessary money for expansion joints. (Expansion joints cost about 0.08 to $0.12 per linear foot of joint and their use increases the pavement cost about $0.02½ to 0.04 per square yard.) Personally, the author believes that all joints should be both expansion and contraction joints and that it is not wise to omit them.

Expansion produces a stress of approximately 13 lb. per degree of temperature where no movement occurs and produces an elongation of free end slabs of approximately 0.008 in. per 100 ft. of road per degree of temperature. For the extreme range of temperature in northern climates, expansion probably does not produce a compressive stress in excess of 1,000 lb. per square inch where expansion joints are not used. This stress will not cause failure of the concrete but is sufficient to cause buckling or blow-ups under certain conditions. Expansion joints permit the free expansion of the individual slabs and prevent internal stresses. The space to be provided depends on the range of temperature expected; for northern climates with a maximum of perhaps 80 degrees above the temperature of construction, an allowance of approximately ¾ in. per 100 ft. is necessary and 1 in. per 100 ft. is not excessive. Where joints are placed every 33 ft., a joint thickness of ⅜ in. is a good allowance; this corresponds with ordinary practice. Such joints are of the premolded type. It is essential that they be constructed in a vertical plane to prevent rising of slabs along the joint due to expansion pressure. It is also essential that a complete separation of slabs is obtained; that is, the bitumen must extend from bottom to top of the pavement and from edge to edge.

It is not difficult to keep these joints vertical on level grades provided reasonable care is exercised as described in the specifications. On grades of 4 per cent or more, however, it is advisable to back them up on the down hill side with 16-gage steel plates as shown in Fig. 115.

Transverse Contraction Joints.—While it seems advisable to make all transverse joints combined expansion and contraction joints spaced about 33 ft., there is considerable tendency to increase the distance between expansion joints to 100 to 300 ft. and to provide intermediate submerged contraction joints at intervals of 30 to 70 ft. Such joints are generally 14- or 16-gage steel plates cut ½ less depth than the pavement. The concrete is screeded and finished continuously over these joints and contraction produces a more or less jagged crack over the top of the plate which tends to spall more under traffic than the rounded edge expansion joint; the argument for these joints is based on a smooth riding pavement but there seems to be no well-defined basis of fact in this contention; these steel plates cost about the same as a ⅜-in. premoulded joint.

TABLE 23.—COMPARISON OF RECOMMENDED THEORETICAL DEPTHS OF CEMENT CONCRETE BASES FOR DIFFERENT PAVEMENTS UNDER DIFFERENT MAXIMUM LOADS ON DIFFERENT SOILS

(In Inches)

NOTE.—The last column gives prevailing practice in base depth for each type (1919 to 1922).

Pavement	Recommended depths of cement concrete bases based on modified corner load formula $d = P\sqrt{\frac{JW}{S}}$						Current practice 1919–1923, inches
	3½-ton truck 16,000-lb. gross load		5-ton truck 22,000-lb. gross load		7-ton truck 28,000-lb. gross load		
	Ordinary subsoils, inches	Gravel or macadam, inches	Ordinary subsoils, inches	Gravel or macadam, inches	Ordinary subsoils, inches	Gravel or macadam, sub-soils, inches	
Plain concrete: (1:1½:3 mix).....	7.2 & 7.8	6.5 & 7.0	7.9 & 8.8	7.2 & 8.0	**8.7 & 9.7**	**8.0 & 8.8**	6 to 10
Plain concrete: (1:2:4 mix).....	7.6 & 8.2	6.9 & 7.4	8.4 & 9.2	7.6 & 8.3	**9.2 & 10.0**	**8.4 & 9.1**	
Reinforced concrete (mesh and bar): Central longitudinal joint (1:1½:3 mix).	6.3 & 6.9	6.0 & 6.4	6.7 & 7.5	6.2 & 6.8	**7.3 & 8.2**	**6.5 & 7.3**	
Reinforced concrete (corner and exterior tie bars only): Central longitudinal joint 1:1½:3 mix..	6.5 & 7.0	6.0 & 6.4	7.0 & 7.8	6.3 & 7.1	**7.7 & 8.5**	**7.0 & 7.7**	5 to 9
1:2:4 mix.....	6.9 & 7.4	6.4 & 6.8	7.4 & 8.2	6.7 & 7.4	**8.1 & 9.0**	**7.4 & 8.1**	
Monolithic brick 4-in. brick on 1:1½:3 concrete base.....	4.5	4.0	5.0	4.5	**6.0**	**5.5**	4.0
2-in. to 3-in. *Asphaltic concrete on concrete base:* (1:3:6 mix).....	6.5	6.0	7.0	6.3	**7.5**	**6.8**	5 to 8
(1:2½:5 mix).....	6.0	6.0	6.5	6.0	**7.0**	**6.3**	
2-in. *Asphalt block on cement concrete base:* (1:2½:5 mix).....	6.5	6.0	7.0	6.3	**7.5**	**6.8**	5 to 8
4-in. *Brick* (mastic joint filler) *on cement concrete base* (1:3:6 mix).....	6.8	6.2	7.6	6.9	**8.3**	**7.5**	
(1:2½:5 mix).....	6.5	6.0	7.0	6.3	**7.8**	**7.1**	6 to 8
4-in. *Brick (cement grout filler):* (1:3:6) concrete base.	5.5	5.0	6.1	5.5	**6.7**	**6.2**	5 to 8
(1:2½:5) concrete base.....	5.2	5.0	5.7	5.2	**6.3**	**5.7**	
5-in. *Stone block: Cement grout filler*..... (1:2½:5) concrete base.....	5.2	5.0	5.7	5.2	**6.3**	**5.7**	5 to 7

NOTE: Where two depths are given the smaller is for interior areas and the larger for exterior edge depths. Where one is given it applies to interior areas.

Typical recommended Pavement Sections showing details are given in Chap. III under the discussion of each type of pavement. The object of this table is to give a tentative basis of estimating the amount of materials and the cost per square yard for the different types suitable for different maximum load conditions.

Table 23 in conjunction with Table 17, page 100, provides a means of computing reliable comparative cost estimates for all ordinary standard types based on equal strength.

Longitudinal Joints.—There are two general types: the submerged steel plate where the entire width of pavement is constructed at one time (see Fig. 115, page 266) and the plane of separation joint where the pavement is constructed in successive strips. The second is the better method as a better line and denser edge is secured. With the submerged joint, the concrete along the center steel is often porous due to lack of care in manipulation; this condition cannot be observed and remedied as well as where the pavement is constructed in successive strips; in the second method, a dense edge is insured as when the forms are stripped, it is easy to detect and correct carelessness in spading along the edge. It is important to get a dense impervious concrete along these joints as water is bound to seep in and the concrete is subjected to its greatest strain at this location.

Design Details.—Design details consider depth, width, crown and detail arrangement of joints and reinforcement.

Depth.—The design of depth was discussed in Chap. II and summarized in Table 23 which is repeated on page 272 for convenience.

Width.—Concrete pavements on rural roads range from 9 to 20 ft. in width. Single track 9-ft. pavements are of doubtful value for if a road has enough traffic to warrant the concrete type of pavement, it certainly

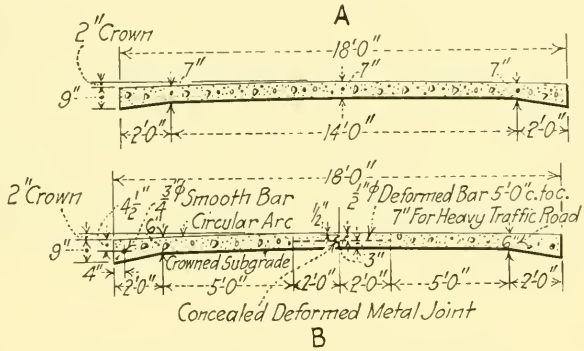


Fig. 117.—State of Illinois 1923 standard.

warrants greater width. These single track concrete roads have not been at all satisfactory in localities with which the author is familiar. Widths of 18 or 20 ft. seem the most logical for conditions which make concrete suitable on rural highways. Extra width on curves was discussed in the first volume of the series and the results summarized in this volume, page 71. Current practice in this matter is indicated in Fig. 10*A*, page 71, of this book. The widths of village streets are discussed in Appendix E. Alleys in business districts should be at least 18 ft. wide; in resident sections at least 16 ft.

Crown.—There are two popular shapes of the crown curve, Parabolic and Circular. The parabolic is easier to figure and for narrow rural

pavements of 18 ft. or less in width which can be struck off by a single templet there is no objection to this type of curve. For wider pavements, particularly for street work, the circular arc is probably better as a single templet can be used for the successive strips without danger of inequalities in the crown. Street *crowns* made up of a curved central portion and inclined plane sides are to be avoided as while this is an easy form to construct, it does not look well as it gives the appearance of a sag in the crown. The circular arc crown is probably better adapted to all conditions.

The difference in elevation between the center line of the pavement and the edge or gutter line varies with width and grade. The adopted height of crown depends on convenience for traffic and appearance. On

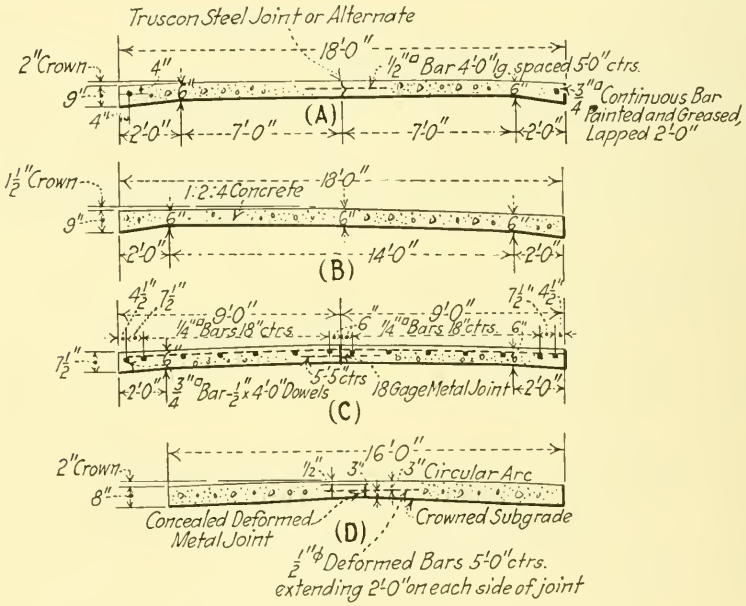


Fig. 118.—Typical state standards (1923), cement concrete roads.

rural highways for widths up to 20 ft., usual practice ranges between 1/8 in. per foot of half width to 1/4 in. per foot. A total crown of 2 in. for 16, 18 or 20 ft. total width of pavement serves very well. This requires a crown radius of from 200 to 250 ft.

On wider pavements and village streets, the range in standard practice is shown in Figs. 137*A* to 137*B*, page 315. Super-elevation and shoulder and ditch grading were discussed in the first book of the series. Standard practice is indicated by Fig. 79, page 211.

In alley work a crown slope towards the center of 1/4 in. per foot is satisfactory. Alleys generally drain toward and along the center line with pick-up catch basins at short intervals.

Detail Arrangement of Reinforcement and Joints.—See Figs. 108 to 118, pages 252 to 274.

Construction Equipment.—Equipment is to be covered in detail in the third book of the series. Excellent suggestions in regard to detail equipment can be obtained from the Portland Cement Association on request. For the benefit of short-course students the following condensed list of equipment and illustrations gives a rough idea of usual practice.

Grading, culvert and rail shipment unloading apparatus the same as for macadam construction, pages 214 to 225.

PAVEMENT CONSTRUCTION

The pavement is mixed by two general methods. Mixing machine on grade with dry batch delivery or central mixing plant with wet batch delivery. The first method is the more common method and is generally

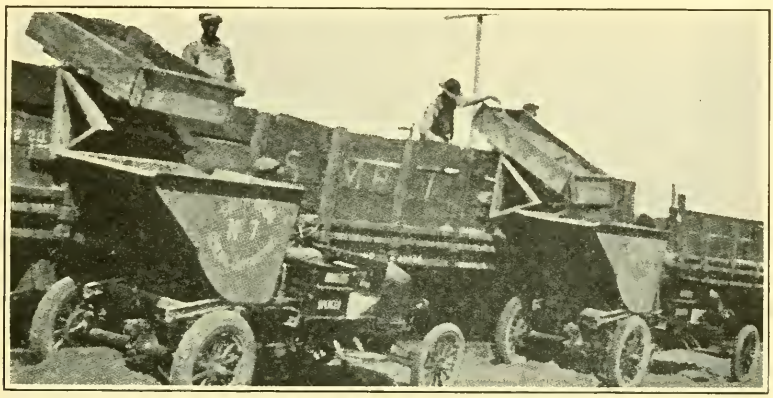


Fig. 119.—Sand batching by volumetric hoppers with quick discharge to small trucks carrying a single batch of concrete (dry batch delivery).

more satisfactory from an engineering standpoint. This method requires a good batch mixer equipped with a timing device and having a capacity of preferably a three bag or larger batch. It can have either a spout or boom and bucket delivery but the boom and bucket is generally the better method. The batches are proportioned at the source of material supply which may be either one central depot located at the railroad unloading point or local pit or they may be stock piles distributed along the road. The proper amounts of stone and sand for each batch can be measured in a number of ways so long as a definite control of quantity is secured. They consist of some form of measuring box easily filled and quickly discharged or transferred into the truck or train which transports the material to the mixer. The batches are carried to the mixer

either by teams, large or small trucks or narrow gage railroad, depending on the size of the job and the general conditions of hauling. For ordinary jobs in ordinary topography with some heavy grades transportation by light Ford trucks carrying from 1 to 2 batches each trip has proved very satisfactory for the following reasons. These trucks if equipped with pneumatic tires make good speed; they do not cut up the grade and if a

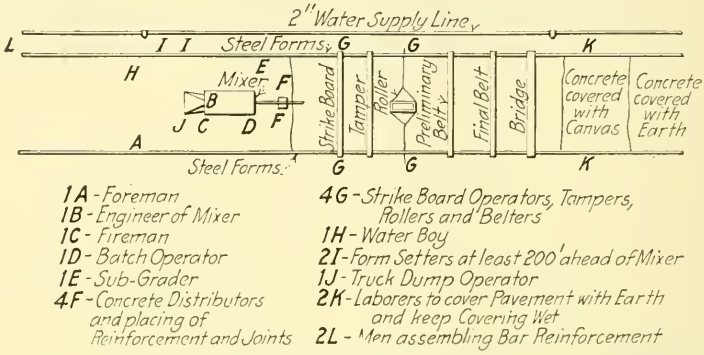


FIG. 120.—Typical organization.

single truck is laid up for repairs it does not seriously curtail the output. Turntables are often used on the grade near the mixer to save time of truck manipulation. Water is supplied to the mixer and for curing purposes by a pipe line. The above sketch and list of equipment on

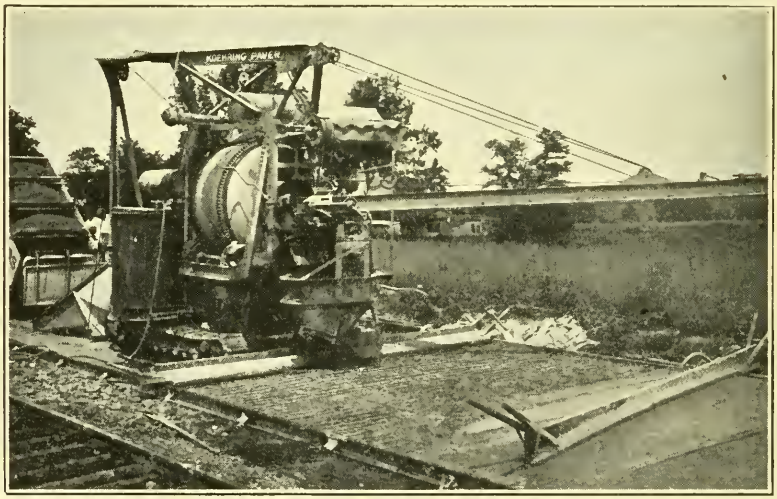


FIG. 121.—Modern mixer with timing device, automatic water gauge, caterpillar traction, loom and adjustable bucket spreading lip. Picture shows dry batch delivery with 5-ton trucks, four batches to a truck.

the grade is taken from a pamphlet of the Portland Cement Association modified slightly and gives a good idea for ordinary procedure. This of course will be varied somewhat on each job.

ORDINARY EQUIPMENT

1,300 to 1,500 lin. ft. of steel forms with necessary pins, line sledges etc. for setting, necessary shovels and spades.
1 standard mixer (preferably boom and bucket).
1 subgrade tester.
1 expansion joint header.
1 screed.
1 belt or board for finishing.
2 toggle joint long-handled floats for finishing.
1 split float for joints.
1 hand float for special work.
1 broom for final finish; burlap cover.
250 ft. mixer hose.
250 ft. sprinkling hose.

Necessary pipe-line equipment which means a supply of about 35 to 40 gal. per minute with a pressure of about 50 lb. per square inch at the delivery point for a 3-bag batch machine.

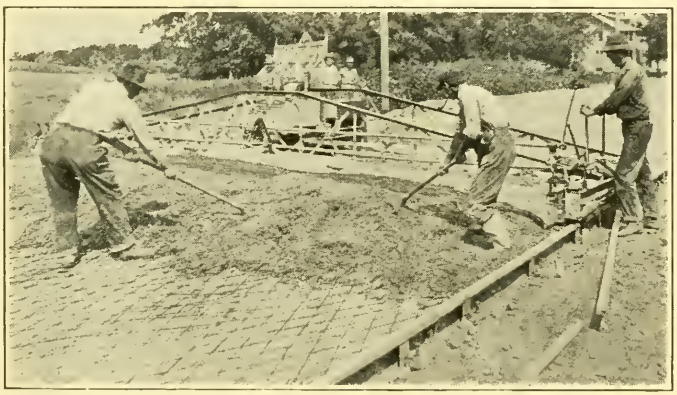


FIG. 122.—Mechanical finishing machine.

Wire knippers and cold chisel for cutting reinforcement.

Inspection.—Effective inspection becomes increasingly important for the rigid types of pavement. The following quotation from a paper by J. H. Wasson emphasizes in an effective way the necessity for careful inspection:

> Let us assume $1 as the unit invested in a concrete pavement and then determine how the road value received from this investment is affected by inefficient inspection. Table 30 will illustrate what is meant.
>
> In Table 30 I have listed the more common shortcomings in concrete pavement construction and have given the estimated effect of each on the finished product. One or more of these are very apt to be found on any poorly inspected job. These values will vary of course.

TABLE 30

Amount invested in pavement	Deficiency	Effect in per cent on strength and quality of slab	Road value received per dollar invested	Cumulative road value received per dollar invested
$1.00	None	None	$1.00	$1.00
$1.00	½ in. shy in depth	12.5	0.875	0.875
$1.00	45 sec. mix instead of 60 sec	6.0	0.94	0.815
$1.00	Too much water 2-in. to 6-in. slump.	10.0	0.90	0.715
$1.00	8 per cent reduction in amount cement specified	8.0	0.92	0.635
$1.00	Sand content increased. Stone content decreased.	6.0	0.94	0.575
$1.00	Improper finish	4.0	0.96	0.535
$1.00	Insufficient curing	10.5	0.895	0.43
$1.00	Uneven riding surface	15.0	0.85	0.28

The real significance of the possible loss due to poor inspection may be seen by considering the amount invested to be $27,000 or about the cost of 1 mile of pavement. When the factors in the last column of the table given above are applied it can be seen that although the mile of pavement cost $27,000 its actual road value may be only $18,045 or even less. In other words, while the cost per mile may vary but a few per cent, the road value received by the public per mile or per square yard may vary 100 per cent or more. There is no question but what from the standpoint of road value received, incompetent inspection on the job is the most expensive thing that can be placed in a concrete pavement, while well paid, competent inspection is the cheapest thing that can be placed in a pavement.

Inspection Details. *Subgrade.*—The earth subgrade must be uniform and well compacted. There is a tendency to underroll subgrades for concrete pavements. The policy of plowing or harrowing and smoothing off the grade just ahead of laying the pavement cannot be too strongly condemned. The practice of last minute small fills to true up the grade is very poor practice as they never can be compacted as well as the balance of the grade. It is much better practice to permit minor inequalities in the grade and require all trimming after the forms are set to be cuts. The idea of strict uniformity of depth with payment on the basis of net concrete section is responsible for a large number of cracks as it encourages loose dirt fills to prevent loss of concrete. It is much better practice to pay the contractor for sand, cement and stone as separate items and to stipulate maximum and minimum depths with an allowance of 10 per cent over the net area to take care of grade inequalities; under these conditions the fine grade can be completed and well compacted and the concrete beds down on a uniform hard grade.

New fills are the greatest source of rigid pavement failures. Where the pavement is to be laid the same year as graded, extreme care must be exercised for fills of over 1 ft. deep. Fills less than a foot deep can be

constructed in one layer and satisfactorily compacted by teaming and rolling; the underlying grade must however be broken up for fills of 6 in. or less to produce a good bond and uniformity of compaction. Fills over a foot deep, must be spread in layers not exceeding 8 in. loose and completely compacted before the next layer is spread. *This means real compaction not bunk. Each layer should be as hard as the usual top finished subgrade.* This can be better accomplished by well-distributed teaming than by rolling and for long fills does not generally introduce much difficulty so long as each layer is started nearest the source of supply and each team drives over the entire length of fill both full and empty. For short deep fills it is often necessary to keep a team with a partial load traveling up and down the fill all the time in lieu of a roller.

Where fills will have a chance to settle for a year 18-in. layers are allowable and no extreme care in compaction is required. If wet weather occurs during the construction of a fill, all mud must be removed before the next layer is deposited, as internal layers of mud dry out very slowly and are always the source of trouble. In many cases fills 3 ft. deep have to be removed and the mud excavated after 3 to 4 months time. It is a distinct money saver to the contractor to be particular in regard to this matter. Before work is stopped each night, the fill should be roughly shaped up to shed water and the surface compaction completed.

Subbase.—Subbase is rarely required under a concrete pavement, it being better policy to deepen the concrete. Where quicksand or muck is encountered, however, subbase is required of sufficient depth to provide a grade which can be compacted with a standard roller; subbase under concrete pavements should be coarse pit run gravel deposited in 6-in. layers and consolidated by teaming or rolling. Boulder stone base is not satisfactory.

Manipulation of Concrete. (Inspection details).—The following quotation from N. Y. Instructions (1923) outlines the main points to be considered in connection with the pavement:

ONE COURSE PLAIN AND REINFORCED CONCRETE

The fundamental requirements to be followed in building a plain or reinforced concrete pavement according to our Standard Specifications are:

1. Properly prepared subgrade.
2. Thorough and complete drainage system.
3. Full depth of pavement.
4. Full cement content.
5. Clean and well-graded aggregates.
6. Proper proportioning of aggregates.
7. Accurate water measurement.
8. Mixing interval to be least one minute.
9. Placing reinforcing material as specified.
10. Proper compaction of concrete.
11. Staking joints securely and placing them exactly perpendicular.
12. Finishing at the proper time and according to specifications.
13. Curing for the full period called for in the specifications.

The surface of this type of pavement can be made even and true and free from waves, irregularities and uneven joints. When defects are found, they are the result of lax inspection and poor workmanship.

Preliminary Preparation.—Before starting to lay the concrete pavement, the inspector must see that the contractor has his concrete mixer, subgrade tester, roller and belt or finishing machine, split float and bridge for finishing at joints, straight-edge, template for reinforcement, edging tools, stone forks, charging conveyances (of uniform size), measuring boxes, steel bulkheads, forms, pins for staking, striking template, reinforcing fabric in flat sheets, expansion joint material in straight full or half lengths, covering canvases and forms for same. The mixer must be equipped with timing and water measuring devices, as well as satisfactory charging skip and discharging chute or bucket as specified. It is necessary that all this equipment, tools and material be first class, and approved by the Division Engineer before the work of placing concrete wearing surface may be started and that they be kept in first class condition during the progress of the work.

Aggregate.—The fine and coarse aggregate shall be well graded clean products, which have been tested and approved by the Engineer of Tests, before being used in the work.[1] Field tests must be made daily for sizing, loam content and organic impurities. The inspector must watch carefully the materials as they are delivered to the work and in the case of rail shipments must have an understanding with the contractor that he must be notified in order that the cars can be inspected for acceptance or rejection before unloading.[2]

Each material must be kept clean and not allowed to become mixed with dirt and other materials. Fine aggregates must be shoveled and coarse aggregates forked from the tops of the piles in order to minimize the chances of picking up dirt. Aggregates that cannot be forked or shoveled clean must be rejected.

Frequent visits should be paid to sand pits and quarries, especially those in which there are questionable materials. In stone quarries, consideration must be given to stripping and the disposal of unsatisfactory waste. Screen openings must be checked and the proper facilities adopted that will insure a thorough mixture of sizes.

Cement must be carefully stored and kept dry. Under no conditions shall it be placed on the ground. Samples of each car, when not tested at the plant in accordance with instructions, must be sent to the laboratory. Pending a report the cement cannot be used.

Forms.—Forms shall be erected only after the subgrade has been properly prepared. The subgrade tester shall be operated from these forms in accordance with the specifications to insure the proper depth for the pavement at all points. The subgrade tester must remain at the mixer at all times and must be used at each move of the mixer. *This stipulation not feasible. It is better to check the grade for a hundred feet ahead of the mixer and then correct any small rutting due to teaming or moving the mixer by eye. A tester under the mixer boom is an abomination.* It must always be used in a vertical position and when being moved shall not be raised from the side forms. A string level should never be used in setting side form. A suitable true, straight edge and three (3) foot carpenter's level must be used and the level must be checked for accuracy by reversing it.

Only straight, substantial, and clean forms shall be used. Wood forms should only be used for curves of less than 150-ft. radius. All unsatisfactory or rejected forms shall be removed from the work.

Wooden forms must be used on curves of 150-ft. radius and less. Sawcuts shall be made at frequent intervals to obtain the necessary true curvature.

All forms must be oiled or greased each time before use. Straightening must be done whenever necessary.

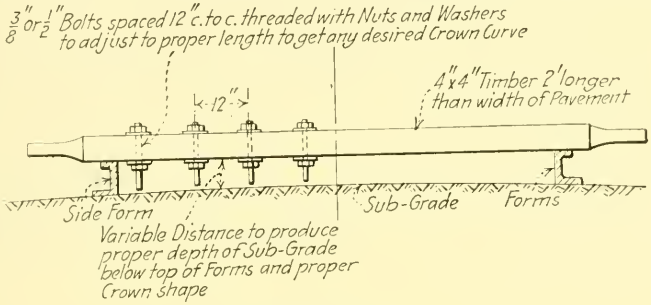
[1] See Appendix A for test methods.

[2] Central batching from large stock is generally specified to prevent dirty aggregate.

Forms must be set accurately and substantially. Poor line and grade are not only annoying in appearance but they result in uneven surfaces and indicate careless work. Forms shall be protected against any disturbances such as dumping materials.

The subgrade must be brought to a true elevation and rolled to a width of at least eighteen (18) inches outside of the form line. The practice of blocking up forms on stones where the subgrade is low and afterwards tamping a loose dirt fill inside and along the form must never be allowed. If the subgrade is found to be too low after forms are placed, they must be removed, the subgrade brought to the proper elevation and rolled for the required width before the forms are finally reset to a full and even bearing on the subgrade.

Two hundred feet on both sides must be set at all times in advance of the mixer. There shall be string line stretches on one side, then checked by eye in order to detect any irregularities. Special attention should be given to joints in forms and when tops of forms do not coincide at these points, the forms should be rejected. Short curves and parts of the tangents should be laid out at the same time in order to get an intelligent check. Middle ordinates for various lengths of chords for the different


3/8" or 1/2" Bolts spaced 12" c. to c. threaded with Nuts and Washers
to adjust to proper length to get any desired Crown Curve
4"x4" Timber 2' longer
than width of Pavement
12"
Side Form
Variable Distance to produce
proper depth of Sub-Grade
below top of Forms and proper
Crown shape
Sub-Grade
Forms

Sub-grade tester.

curves should be at command, in order to eliminate kinks and uneven curves. A line of forms shall be securely staked to this string line and then the opposite side placed. Care must be used to get the proper width and elevation for opposite forms.

Curves shall be widened and super-elevated in accordance with standards when indicated on the plans.

Grades as shown on plan shall be on the normal center line of the roadway on super-elevated curves. No concreting shall start on a widened curve until forms are erected and checked on both sides.

All forms must be removed within twenty-four (24) hours after concreting.

The inspector should carefully examine the edges of the pavement immediately after the removal of side forms and if concrete is honey combed have it sealed with cement sand mortar, afterward insisting on a more adequate spading of the concrete adjacent to side forms.

Measuring Devices, Checking Quantities and Composition.—Proportions shall not be varied for any reason without approval of the division engineer. The correct measuring of all materials is essential in securing satisfactory work.

The contents of all proportioning boxes and batch boxes must be determined by accurate measurements and such changes as are necessary in regulating the proportioning, must be made prior to beginning operations.

The inspector must keep accurate check on the amount of cement used and maintain a daily record of the length of pavement laid and the quantities of cement required and used.

The inspector shall arrange for the weighing of an occasional bag of cement to see that they contain ninety-four (94) pounds net (with an allowed variation of five (5) per cent) and must be sure that the man dumping cement shakes the bag well in order to get the entire amount out of the sack.

The number of empty bags must be counted about every 2 hours and then placed in separate piles or removed from the work. This method will relieve the accumulation of any shortage or excess.

The use of industrial systems will require one inspector at the material yards. Cars on which the aggregates are measured direct, must have separate and vertical compartments for each kind of aggregate and must be of the exact size of the batch, in order to insure correct proportions.

Combined aggregates shall not be permitted to be measured in vertical containers of one opening. In this case especially arranged measuring devices must be used for each aggregate from which the container can be filled.

Care must be used in protecting the cement against wind during the loading process. If necessary, erect a canopy. In cars when the cement will be exposed, lids or covers must be used at all times. Under no conditions permit cement that cannot be used immediately to be loaded on industrial cars.

Some jobs will require different methods than these, depending on the contractor's equipment. Consideration must be given and if there are any unusual features, the Division Engineer should be called to the work for final decisions as to the methods to be used by the inspector.

Consistency.—The consistency of concrete is very important because the strength is greatly reduced by the use of excess water. Only sufficient water shall be used that will form a concrete similar in consistency to moist (not wet) earth when a finishing machine is used and quaking wet for hand finishing.[1] The Inspector must note the moisture of the sand in order to vary, whenever necessary, the amount of water.

The contractor shall be required to have a glass gage on the mixer in order to visually determine the quantity of water for each batch. Examination must be made of all valves and pipes in the mixer to detect leaks which cause non-uniform amounts of water per batch.

The concrete must be particularly dry for finishing machine work. A wet concrete would not only be low in strength but a scale of mortar may be formed which will peel off in course of time under traffic. Frequent examinations throughout the day's work should be made in the recently finished concrete by inserting vertically a blunt end of a pencil in the surface in order to detect excess mortar. There should be only sufficient mortar to completely cover the coarse aggregate.

Non-uniformity in the consistency of the concrete results in uneven surfaces; therefore, the inspector must correct at once faults in the water supply system of the mixer and not allow the work to proceed until these faults have been found and corrected.

After the pavement is finished and before it hardens be sure that no stones project above the surface or that the surface appears honey combed. Have these faults corrected by using a hand float or the reapplication of the finishing machine.

Mixing.[2]—The concrete mixer must be equipped with approved timing and water-measuring devices and an approved device for discharging the concrete, all of which must be kept in workable condition at all times. The time, as noted in the specification, must be strictly adhered to. The concrete must not be discharged until the full time has expired. At frequent intervals the Inspector should check the time of mixing. The time of mixing shall be measured from the time the last material enters the drum from the loading skip until the first material is discharged into the bucket.

[1]Avoid extremely dry concrete as under the usual inspection better results are obtained with a fairly easy flowing consistency.

[2]For effect of time of mixing on strength, see Appendix F.

The skip shall not be dumped into the mixer until the previous batch has been entirely discharged, otherwise non-uniform mixes will result.

Placing.—Concrete shall only be placed on a subgrade which has been tested by means of a subgrade tester placed at the discharge end of the mixer. The subgrade must be firm and smooth and all loose material removed. Loose material along the forms must be removed by means of a square point shovel or spade.

Fig. 123.—Placing concrete with hand lute where special surface shape makes it impossible to use standard strike board.

The first layer of concrete shall be deposited to the depth of fabric reinforcing, two (2) inches below the surface of the pavement and struck off with an approved template. Rod reinforcement shall be placed three (3) inches from all transverse expansion and construction joints and at a depth equal to two (2) inches.

The fabric reinforcement must be perfectly flat when placed in the work. If furnished in rolls, it must be flattened by the use of a machine. The fabric must extend to within two (2) inches of all sides and must be lapped as specified. It must be protected before use from the weather except as required from day to day. Under no condition shall it be stored in the open, especially during the winter months.

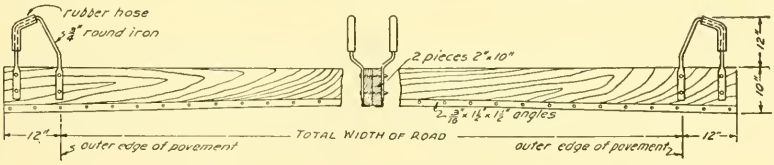


Fig. 124.—Strike board.

The fabric reinforcement is placed two (2) inches below the surface. A striking template insuring a two (2) inch depth must be used.

After the placement of fabric reinforcement, the remaining two (2) inches of concrete is placed. It must be placed of sufficient depth to have a slight excess ahead of the strike board for finishing. Do not permit the workmen to walk on this concrete after the initial spreading.

Evenness of finished pavement surface is insured by the proper even spreading and distribution from the drop bucket of the mixer. Uneven distribution and attempts to fill in low places with mortar results in a wavy surface which is only detected after the mortar has hardened.

Finishing.—As soon as the full depth of concrete has been spread, it shall be struck off, either by a hand template or approved finishing machine. A slight excess of concrete must be maintained ahead of the strike-board. Depressions and holes must be filled with concrete, not mortar, and must be retamped.

A hand template must be specified length and weight. It shall be first worked in a crosswise movement and then followed by tamping to insure a proper cross-section and the imbedding of coarse aggregate. The template shall be operated until within two (2) feet of an expansion joint, and then lifted to the joint and worked back from

FIG. 125.—Rolling concrete by hand. Concrete in this picture is a little too wet for the best results.

the joint. Excess mortar and concrete must be carefully removed and in no case be permitted to remain. Templates (both hand and finishing machine) must be checked frequently for crown.

Immediately after tamping, the sides must be spaded continuously in order to prevent honey combed sections and to insure satisfactory edging. Any excess mortar or concrete must be removed. *The sides along the bulkhead and filler must be spaded to insure dense surfaces and to ease the lifting of the bulkhead against raising the filler.*

Hand tamping shall be followed by a roller of standard dimensions and weight. The use of roller must not be delayed until the surface is partially set, otherwise, the concrete will be lifted. Too early rolling will remove too much mortar and not water. The roller must be moved slowly, not to exceed 16 ft. in 40 seconds, and must be passed over and back, the roller then being lifted and advanced one-half its length, the rolling operation then being repeated. The first rolling must proceed from the end of the slab first laid and free water must be allowed to come to the surface between each rolling. The roller must be wetted after each operation and kept clean and true in form.

Belting of the surface shall follow. The belt shall be kept moist or oiled and cleaned at all times, in order that the full width can rest on the pavement. The belt must not be so heavy as to mark the finished surface. The belt shall be operated in a crosswise movement, so that any part for the total width and breadth rests on the pavement.

There should be two beltings. The first must be slow to take out irregularities, remove excess water and smooth the surface. The second shall be a little faster in the forward motion to give the finish and prevent markings. Never permit a belt to remain on fresh concrete.

Approved finishing machines may be used in place of hand work. When such is the case, it is necessary for the contractor to have equipment for hand work which can be resorted to in the case of a breakdown in the finishing machine.

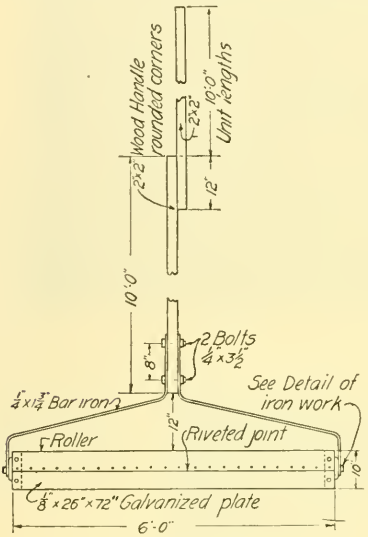


FIG. 126.—Detail of roller.

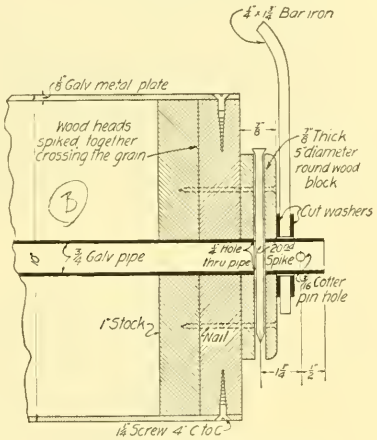


FIG. 126A.—Detail of roller.

In the use of a finishing machine, there is a tendency of the operator to perform too many operations with the result that excess mortar accumulates. The operator should be so instructed and trained, as to finish the pavement with one or two strikings, one or two tampings and two beltings. The parts of the machine for all operations must at all times be regulated to insure contact with the surface at all points. The belt must be kept moist.

On grades exceeding three (3) per cent the surface of the pavement must be rolled with a hand roller following the passage of the finishing machine in the manner prescribed for finishing by hand.

One of the most frequent defects in finishing machine work is that of irregular wavy surface. This is frequently caused by the machine moving too fast, the use of the machine for spreading by carrying an excess of material in front of the blade, failure to feed properly sufficient material by hand to the tamper and most often by running the tamper while the machine is not moving. The finishing machine should move forward at a uniform rate of speed. The blade should not be used for moving any considerable amount of material, only sufficient material being kept in front of the blade to produce a full section. After the finishing machine has come to a stop,

before the tamping is resumed, the machine should be moved back a few feet and then started forward, and the tamping not resumed until the machine has moved forward for at least one foot.

Edging shall not be done too early after the belting.

Curves shall be widened and super-elevated where necessary. On transitions, intermediate pins must be set exactly to grade at beginnings and endings, together with one or two in between sections.

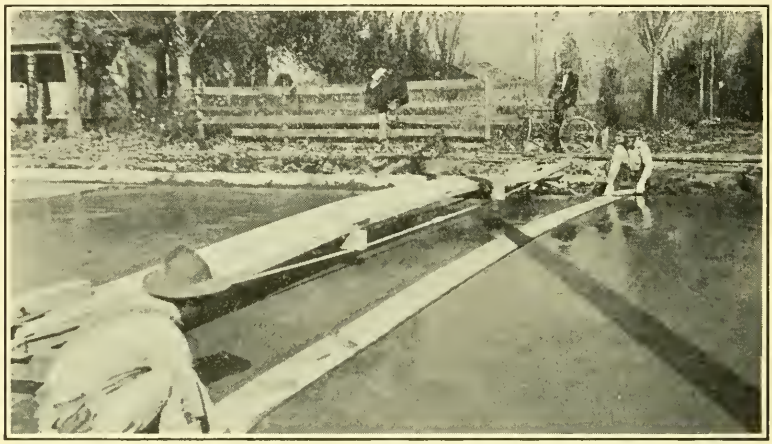


FIG. 127.—Finishing with belt.

The finished crown should be checked frequently by using a string and small blocks the height of the crown, the blocks being placed on the side forms and a string stretched from top to top of blocks. To insure a proper crown it is frequently necessary to have the template shaped to an arc one-quarter (¼) of an inch greater than the required crown to offset the slump of the concrete during hardening.

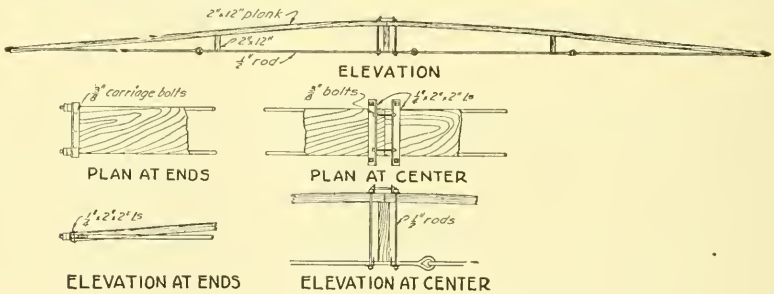


FIG. 128.—Sight bridge for finisher.

Joints.—All expansion and construction transverse and longitudinal joints must be vertical, level and free from irregularity. Irregularities caused by improper and careless work produce defects in the pavement such as one slab raising higher than the other and additional cracks.

Before using joint filler, it must be checked for all dimensions and quality. Many poor results are obtained by joints that are too short and of insufficient depth. Shear-

ing of the edges and sides of concrete under expansion ruptures the concrete and causes spalling.

Joint filler must be furnished in flat sections. No brand of filler shall be used unless approved by the Engineer of Tests.

Only when indicated in the specifications may minimum lengths be connected as one continuous length. These short lengths must be joined by lacing, staples or other suitable means before being installed.

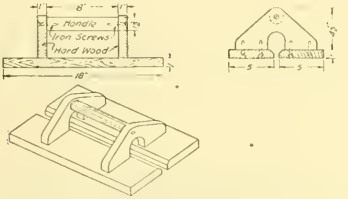


FIG. 129A.—Split float for finishing joints.

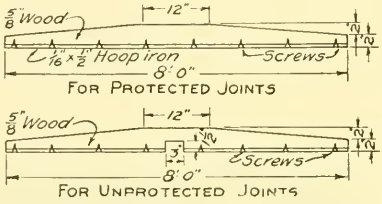


FIG. 129B.—Straight edge for testing surface near joints.

The steel bulkhead shall be of exact dimensions and oiled or greased at all times. The workmen shall be required to lay it on a flat area when not in use, in order to keep it perfectly straight. Any kinks must be straightened immediately after being noticed. It shall be firmly staked on the side towards the mixer with iron pins, the number and length depending on the subgrade conditions and methods of finishing. The joint filler shall be set on the side of the bulkhead away from the mixer.

A steel bulkhead against which the expansion joint filler is placed must be firmly supported by at least ten (10) iron pins, twelve (12) to eighteen (18) inches in length

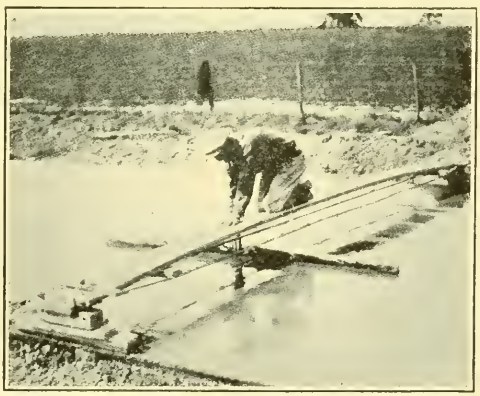


FIG. 130.—Inspector testing concrete surface with straight edge.

depending on the subgrade. Five (5) pins along both sides of the bulkhead and filler with tops two (2) inches below the surface.

These pins must be long enough and are to remain in place in order to insure straight joints in all directions. When joint filler is placed directly against hardened concrete five (5) pins shall be used on the side away from the concrete.

The joint filler should be set just flush with the pavement.

A small amount of spading shall be done along the oiled or greased bulkhead in order to ease removal. The bulkhead shall not be removed until at least 10 ft. of

concrete has been placed ahead and the striking and the tamping has been done on either side or immediately over it. No striking or tamping shall be permitted after the bulkhead is removed, other than just enough tamping with a rod to fill the cavity left by the bulkhead. The bulkhead shall be removed by raising opposite ends at the same time through holes in either end, into which hooks are inserted.

After the removal of the bulkhead on hand finish work when the filler is higher than the surface, a split float or straight-edge in accordance with the standards, shall be used after which the edging tool of ⅛-in. radius is operated on either side.

For finishing machine work, where the filler is slightly raised or flush, the edges shall be rounded with the above radius tool. All joint finishing shall be done by a skilled workman from a finishing bridge. *On no work shall connected concrete be permitted to remain over the filler, as this condition causes serious spalling under traffic.* Edging is to be done along construction joints with the ⅛-in. radius tool.

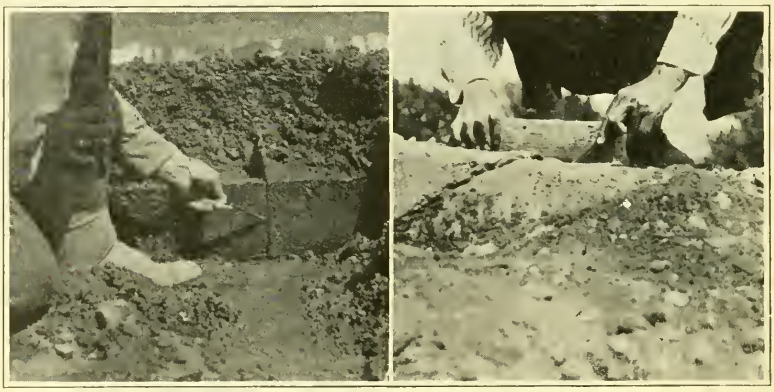


FIG. 131*A*.—Proper vertical joint. FIG. 131*B*.—Improper slant joint.

The belt should be operated immediately on each side of the joint, so as to give a uniform appearance to the entire surface.

The surface of pavement adjacent to joints must be finished with the utmost care by an experienced workman in order to obviate uneven joints which induce an uneven, bumpy riding surface. The six (6) foot straight edge must be used in testing all surfaces adjacent to joints prior to the last belting of the surface and when the surface is uneven it must be corrected.

As soon as forms are removed, investigation must be made to determine if any fillers do not extend entirely through from one side to the other. If not, the contractor shall open the connected sides by means of a chisel. Under no condition permit shoulder material to be deposited along the sides until there is positive assurance that the joints are open.

Protection.—The surface shall be protected with canvas as specified. The canvas shall never be dragged over the surface of the green concrete. In warm weather when the temperature is above 70 deg. F., the surface of the concrete shall be thoroughly wetted as soon after it is finished as it is possible to do so without injuring the surface, the canvas carried over the concrete and lowered vertically onto the surface, and the canvas kept wet. A set of frames to support canvas covering shall be kept on hand at all times near the concreting work to be used in the event of warm or rainy weather, as the canvas must not be laid on fresh concrete. In cool weather the canvas may be dispensed with. Hair checking or cracking can sometimes be eliminated by spraying fresh concrete, using a nozzle that will produce a fine spray

or fog but care must be taken not to use a nozzle that will cause pits in the surface. If this does not prevent hair checking and the materials are dry, they should be thoroughly wet down before they are placed in the mixer. As soon as the surface has hardened sufficiently so it will not be injured, the canvas shall be removed. It must be thoroughly wetted and covered with earth or other approved material at least two (2) inches deep, which must be kept wet at least eight (8) days by sprinkling with water, except in cold, late fall weather. When straw is used in place of earth for covering, the straw should be spread to a minimum depth of four (4) inches and kept wet for a period of at least eight (8) days during warm weather. Straw shall remain in place for a period of at least eighteen (18) days under the most favorable conditions. All persons must be kept off the concrete surface for 3 days. All traffic must be kept off the surface for the full time specified and in the late fall, the time of curing must be extended one week. After the specified time has elapsed, the covering material shall be removed and the pavement swept clean. If found necessary, owing to local conditions, the contractor must furnish a watchman at all times to secure the required protection. In some instances it may be necessary for the contractor to construct temporary foot bridges over the surface of the concrete to permit the necessary passage of pedestrians or cattle from one side of the road to the other."

Concreting during Rain Storms.—Inexperienced inspectors are sometimes puzzled to make a reasonable interpretation in regard to stopping work on account of rain and they worry their heads off if they see a cloud the size of a hand in the sky. From a practical standpoint it is safe to instruct them not to worry; that in case of rain the men will quit before it rains hard enough to do any serious damage; as a matter of fact a light rain gives an excellent spray surface finish much superior to any hand manipulation and I have never had any concrete seriously damaged even by hard showers; if the men quit in the midst of a block and leave the work without heading up it is necessary to reject and dig out a few feet of the pavement to get a good vertical connection.

Protection of Concrete in Warm Weather.—Hot sun and drying winds damage the surface wearing power of concrete pavements and also often

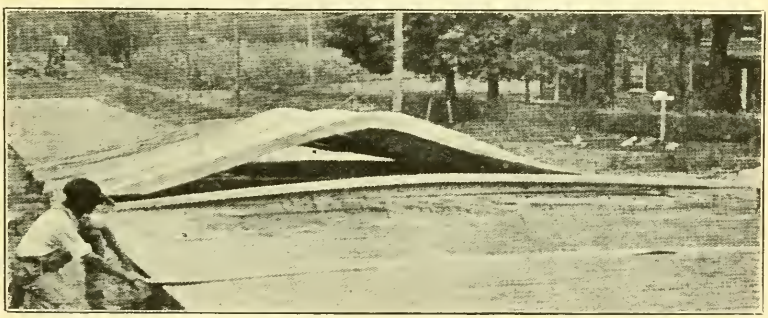


FIG. 132A.—Canvas cover to protect fresh concrete temporarily from sun and wind.

produce so-called temperature and wind checks which are unsightly to say the least. Concrete should be protected in hot weather in order to get the best results; the methods usually adopted are burlap or canvas covers

FIG. 132*B*.—Earth cover and sprinkling. Used from second to tenth day of curing.

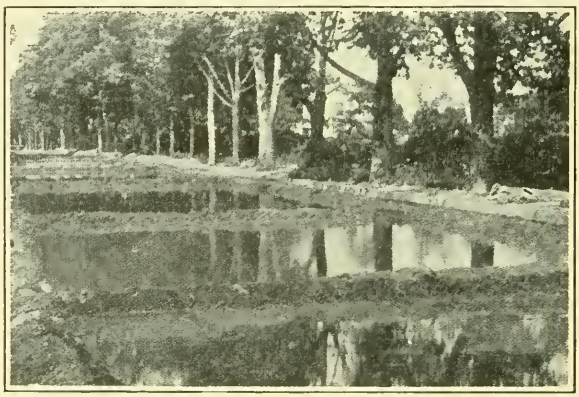


FIG. 132*C*.—Ponding method applicable on level grades up to about 2 per cent.

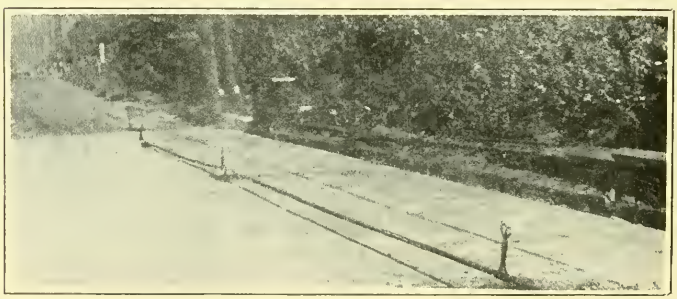


FIG. 132*D*.—Spray sprinklers applicable where water supply is plentiful and pressure good.
FIGS. 132*A* to 132*D*.—Different methods of protecting concrete in hot weather.

on frames, pending, earth cover sprinkled or continuous spray sprinkling. Special protection of this kind is not necessary when the temperature in the spring or fall of the year gets below 50 to 60 deg. The methods used are illustrated by Figs. 132*A* to 132*D* taken from a pamphlet published by the Portland Cement Association. Surface checks (short hair cracks) are difficult to prevent under a hot sun and strong dry wind as they develop before the finishing is complete and before it is possible to protect the concrete by canvas covers. Under these conditions a light spray applied continuously after the surface is belted seems to help reduce these checks. If they do form, a fairly satisfactory repair is too omit the earth cover till the next day and after the surface is fairly dry fill the checks with dry cement; this is done by sprinkling it along the checks and pushing it in with a small broom.

Concreting in Cold Weather.—Cold weather work in connection with concrete paving is a rare emergency and should only be permitted to finish a short piece of incomplete work. With the utmost care results are rarely good as concrete in pavements cannot be as well protected as building concrete under unfavorable weather conditions. Concrete should never be placed on a frozen subgrade.

The simplest solution where an unexpected cold snap develops is to heat the aggregates and protect the concrete by covering with canvas, straw, sawdust or manure. The addition of calcium chloride (3½ per cent by weight) to the mixing water will prevent damage if the temperature does not fall below 28 deg. A simple method of using this chemical which has the property of reducing the freezing point of water and hastening the set of concrete is described as follows in "Recommended Practice" Portland Cement Association: "It can best be added to the mix by making a concentrated solution 1½ lb. per gallon of water; this concentrated solution is added to the mixing water at the rate of a gallon per sack of cement used." This treatment adds about 15c. per cubic yard to the cost of the concrete. Chemical means alone should not be relied on to prevent damage; heating and cover should also be used.

Inspection and Engineering Records.—Inspectors should be required to turn in daily signed records of the essentials in connection with the pavement work. These records are very useful in case of dispute or lawsuits.

The following forms have been used by the author. They can be easily and quickly filled in. They are prepared in book form of pocket size. Two inspectors are usually required: a batch inspector who is responsible for the measurement and quality of the materials and an inspector at the mixer responsible for the grade, forms and manipulation.

MATERIAL INSPECTOR'S REPORT

Name of Road—

Date—Sept. 21, 1922.

Inspector's Signature—John Doe.

Materials Received on Job.

Cement

Car Nos.	Amount	Brand	Acceptance No.
L. & N. 21435	231 bbl.	Atlas	B.R. 2645

Sand

Car Nos.	Amount	Source	Test No.
L.V. 25462	110,500 lb.	Continental	B.R. 1750
Penn. 175133	104,700 lb.	Oaks	Field No. 7

Stone

Car Nos.	Amount	Source	Test No.
L.V. 10546	103,400 lb.	LeRoy	B.R. 1120

Materials Delivered to Mixer

Cement	304.5	bbl.
Sand, approximately	115	tons
Stone, approximately	170	tons

PAVEMENT INSPECTOR'S REPORT

Name of Road—

Date—Sept. 21, 1922.

Inspector's Signature—Richard Roe.

Approval of Grade and Forms

Sta. to Sta.	Time of Approval
25 + 30–28 + 20	7 A.M.
28 + 20–30 + 50	1 P.M.

Tests of Mixer (twice daily)

Time of Mix per Seconds, Batch	No. of Revolutions per Batch	Time Test Made
58	15	8 A.M.
59	15½	3 P.M.

Concrete Data (4 times daily)

Sta. to Sta.	Cubic Yards	Cement	Cement Factor	Time
25 + 30–26 + 80	60.0	117.50	1.96	10 A.M.
25 + 30–27 + 35	82.0	158.25	1.93	1 P.M.
25 + 30–28 + 05	110.0	210.00	1.91	3 P.M.
25 + 30–29 + 23	157.2	302.00	1.92	6 P.M.

Remarks

Previous day's run covered with earth and sprinkled.
Previous day's run shows satisfactory edge.
Cement Tally by batchmeter disagrees with material inspector by 2.5 bbl.

Sample Engineer's Diary.

The diary of the Engineer in charge shows all essentials of the work for purposes of record and possible lawsuits.

Name of Road—_____

Date—Sept. 21, 1922.

Engineer—John Smith.

Engineering Force

John Smith—General Supervision
John Doe—Materials
Richard Roe—Pavement Inspection.
Headquarters Inspector visited work.

Contractor's Work.

Force—70 men
8 teams
8 Ford trucks.

Work—Steam shovel Station 200 to 201
Fine grade sta. 80 to 90
Concrete Pavement Sta. 25 + 30–29 + 23
Cement factor 1.92.

Materials Delivered

Cement L. & N. 21435	231 bbl.
Sand L.V. 25462	110,500 lb.
Penn. 175133	104,700 lb.
Stone L.V. 10546	103,400 lb.

Correspondence—See letter attached giving ruling on maximum cement factor.

Sept. 21, 1922.

Mr. John Brown,
Contractor,
City.

Dear Sir:

The following letter (a copy of which has been sent to the Division Engineer) states definitely my attitude and ruling as Engineer in charge of Road No. ——, in regard to the amount of Cement that I can properly certify for payment as used in the Concrete Pavement work. If you are dissatisfied with this ruling you can appeal to the Division Engineer. The following ruling will apply for all estimates unless I receive definite written instructions from the Division Engineer to modify this ruling. This letter is sent to you at this time in order to give you ample time to make any necessary changes in your batching procedure so that there will be no loss to you on the cement item on completion of the road. This formal action is necessary as your cement factor has been excessively high.

I will certify for payment all Cement actually used in Pavement Work up to an amount which produces an average cement factor for the entire job of not to exceed 2.02 bbl. per cubic yard of Concrete Pavement. I will not certify to any total final excess of cement used over and above this limit on the ground that it is due to careless batching of the sand and stone. In order to give you ample opportunity to avoid final loss I will certify the pavement as satisfactory where the daily cement factor does not fall below 1.80 but will not accept any pavement concrete having a lower factor than 1.80 as reported by my inspectors four times daily. You are to continue using three whole bags of cement per batch and any variations in your procedure are to be made in connection with the sand and stone.

This ruling is based on the following data.

The amount of cement provided in your Contract is based on 1.90 bbl. per cubic yard of Concrete Pavement 1 : 1½ : 3 mix. Based on previous construction experience with this mix I instructed you to use for a three bag batch 4.50 cu. ft. of sand and 9.00 cu. ft. of stone. Under this basis of proportioning properly and accurately batched it has been my experience

Summarized Specifications

State	Date revised	Fine aggregate			Coarse aggregate					Aggregate on subgrade	Mixing						Consistency		Forms		
		Number of screen sizes specified	Colorimetric test specified	Maximum size, inches	French coefficient	Maximum size, inches	Minimum size, inches	Use slag	Use pit run		Cement, barrels per cubic yard	Proportions	Mixing time in minutes	Timing device required	Materials to be measured	Water to be measured	General provisions only	Slump test required	Wood	Steel, pounds per foot	Oiled or soaped
Alabama	....	4	O	¼	8	2	¼	–	O	O	O	1: 2 : 3	1	–	–	–	..	–	–	–	–
Arizona	....	4	O	¼	8	2	¼	O	O	O	O	1: 2 : 3½	1	..	–	–	–	–	–	–	–
Arkansas	....	2	O	¼	10	1¾	¼	O	×	O	O	1: 2 : 3	1	O	–	–	–	–	–	–	–
California	....	3	O	¼	10	2½	¼	O	O	O	O	1: 2 : 4	1	–	–	–	–	–	–	–	–
Colorado	....	4	O	¼	10	2	¼	O	×	O	1.7	1: 2 : 3	1½	O	–	1	O	O	–	–	–
Connecticut	....	3	O	¼	7	2	¼	Crushed rock only		O	O	1: 2 : 4	1½	O	–	–	–	O	–	7	O
Delaware	....	3	O	¼	12	2¾	⅝	O	O	×	O	1: 2 : 4	1½	–	–	–	–	O	O	8	–
Florida	....																				
Georgia	....	3	–	¼	8	2¾	¼	–	O	×	O	1: 2 : 4	1	O	–	–	–	O	O	–	–
Idaho	....	4	O	¼	10	3	¼	O	O	–	1.7	1: 2 : 3	1	..	–	–	–	O	–	–	–
Illinois	....	4	O	¼	6	2	¼	O	×	×	1.61	1: 2 : 3½	1	–	–	O	–	O	–	–	–
Indiana	....	4	O	¼	8	2½	¼	–	×	–	1.70	1: 2 : 3	1	O	–	–	..	–	–	6½–9	–
Iowa	....	2	–	.185	8	2½	.185	O	–	×	1.6	1: 2 : 3½	1	O	–	–	..	–	–	–	–
Kansas	....	3	–	¼	6	2	¼	O	×	×	1.61	1: 2 : 3½	1	–	–	–	..	–	–	–	–
Kentucky	1922	4	O	¼	3.3 6.6	2½	¼	O	×	–	1.4	1: 2 : 3½	1¼	O	–	–	..	–	–	–	O
Louisiana	....																				
Maine	1922	3	O	¼	7	2	¼	O	×	×	1.61	1: 2 : 3½	1	–	–	–	–	–	O	–	O
Maryland	1922	–	O	¼	10	2¾	⅜	O	O	O	O	1: 2 : 4	1	–	–	–	–	–	O	–	O
Massachusetts	1922	4	O	¼	8	2	¼	O	O	O	O	1: 2 : 4	1½	–	–	–	–	O	O	–	O
Michigan	1922	5	O	¼	7	2	⅛	O	×	O	1.83	1: 1½: 3	1	–	–	–	..	–	O	8½	O
Minnesota	....	4	–	¼	8	2¾	⅛	O	×	×	1.54 1.44	*1: 2 : 3½	1	–	–	–	..	–	–	–	O

Mississippi	....																				
Missouri	....	3	○	¼	○	1½	¼	○	×	○	1.7	1:2 :3	1	○	–	–	–	○	–	–	○
Montana	....	4	○	¼	○	3	¼	○	×	○	1.7	1:2 :3	1	○	–	–	–	○	–	–	–
Nebraska	1922	3	–	¼	8	2	¼	○	–	○	1.74	1:2 :3	1	○	–	–	..	–	–	–	–
Nevada	....	3	○	¼	8	2½	¼	○	○	○	○	1:2 :4	1	○	–	–	–	○	–	–	○
New Hampshire	....	3	○	¼	8	2	¼	○	×	○	○	1:2 :3	1½	–	–	–	–	○	–	–	–
New Jersey	1922	5	○	¼	10	3	½	–	○	×	1.91 1.51	1:1½:3 1:2 :4	1½	–	–	–	..	–	○	–	*b*
New Mexico	....	..	..	..	8	2½	¼	○	○	○	○	1:2 :3	1½	○	–	–	–	○	–	–	–
New York	....	3	○	¼	7	2¾	¼	–	×	×	○	1:1½:3	1	–	–	–	–	○	On curves only	–	–
North Carolina	....	3	○	¼	8	2¾	¼	○	○	×	○	1:1½:3 1:2 :4	1½	–	–	–	–	○	×	7	–
North Dakota																					
Ohio	1922	5	○	¼	7–8	1½	¼	–	×	○	1.75–2.0	1:1½:3	1	*b*	⌐	–	..	–	○	–	–
Oklahoma	1921	3	○	¼	7	2	¼	○	○	○	○	1:2 :3	1½	○	–	–	–	○	–	–	–
Oregon	....	2	○	¼	8	3	¼	○	○	○	1.66	1:2 :3	1	*b*	–	–	..	–	–	–	○
Pennsylvania	....	3	○	⅜	8	2¾	⅝	○	○	×	○	1:2 :3	1¼	–	–	–	–	○	On curves only	6½	–
Rhode Island	....	4	○	¼	8	2	¼	○	○	○	○	1:2 :3	1	–	–	–	–	○	○	–	–
South Carolina	....	3	○	¼	8	3	¼	○	○	○	○	1:2 :4	1	○	–	–	–	○	–	–	–
South Dakota																					
Tennessee																					
Texas	1922	3	○	¼	8	2	¼	○	○	○	○	1:2 :3½	1	–	..	–	..	–	–	–	–
Utah	....	4	○	¼	7	2	¼	–	○	○	○	1:2 :3	1	○	–	–	..	–	–	–	–
Vermont	1922	4	○	¼	8	2	¼	○	○	○	○	1:2 :4	1	○	–	–	–	○	–	–	–
Virginia	1923	4	○	¼	8	2	¼	–	○	○	○	1:2 :4	1	–	–	–	..	–	–	–	–
Washington	....	3	–	¼	○	3	¼	○	○	–	1.66	1:2 :3	1	–	–	–	–	○	–	○	–
West Virginia	1921	4	○	¼	7	2½	¼	–	○	○	○	1:2 :2½	1	–	–	–	..	–	–	–	○
Wisconsin	1921	4	–	¼	7	2	¼	○	○	..	1.5	1:2 :4	1	†–	–	–	..	–	–	–	○
Wyoming																					

Notes: *a* As shown on plans.
b Where required.
c With special permission
– Required or allowed.
× Specifically prohibited.
○ Not required or not mentioned.
* 1:2:4 when machine finished.
** Expansion joints at noon, night and ends of vertical and horizontal curves.
† Central mixing plants and chute mixers prohibited.
Expansion joints omitted in July and August.

SUMMARIZED SPECIFICATIONS—*Continued*

State	Joints					Finishing						Curing						Reinforcement			
	Expansion specified	Width of expansion, inches	Spacing	Longitudinal center joint	Dowels across construction joint	Hand template weight, pounds per foot	Split float	Wood float	Roller and belt	Machine	Allowable surface variation	Canvas or burlap cover	Wet earth or hay-straw	Ponding	Days kept wet	Days kept covered	Days kept closed	Required	Mesh, pounds per 100 square feet	Bars	Distance (inches) from top
Alabama	—	¼–½	*a*	○	○	11	—	○	—	—	○	—	—	*c*	18	18	21				
Arizona	○	. . . . .	. . . .	○	○	11	—	○	—	—	¼″	—	—	—	14	20	30	○			
Arkansas	—	¼–½	37½	○	○	11	—	○	—	—	○	—	—	○	7	14	19				
California	○	○	○	○	○	—	○	—	Roller	○	○	—	—	—	10	○	30	—	○		*a*
Colorado	—	¼	30	○	○	—	—	○	—	○	¼″	○	—	—	10	14	14	—	25	○	2
Connecticut	—	½	25	○	○	12	—	○	—	×	○	—	—	○	8	8	11				
Delaware	*a*	. . . . .	. . . .	. . . .	—	25	○	○	—	—	1/16″ per ft.	—	—	—	14	30	30	○			
Florida																					
Georgia	*a*	1	○	*b*	○	—	○	○	Roller	○	¼″ in 10′	○	—	○	10	18	21	—	44	○	2
Idaho	×	. . . . .	. . . .	○	○	—	○	○	—	—	○	—	—	○	10	○	20	*b*	○	—	○
Illinois	○	. . . . .	. . . .	—	—	*c*	○	*c*	—	—	¼″ in 10′	—	—	—	14	20	30	○			
Indiana	○	. . . . .	. . . .	○	—	—	○	○	—	—	¼″ in 8′	—	—	—	14	21	30	*a*	—	—	*a*
Iowa	×	. . . . .	. . . .	○	—	—	○	○	—	—	¼″ in 10	*b*	—	—	10	25	28	—	○	—	○
Kansas	*a*	½	35	○	○	11	—	○	—	—	○	—	—	—	14	20	30	—	40	—	2
Kentucky	—	½	30	○	○	8	—	○	—	—	¼″ in 10′	—	—	—	14	20	30	—	40	—	2
Louisiana																					
Maine	—	¼	40	—	—	11	—	*b*	—	—	¼″ in 5′	—	—	—	18	18	21	*a*	○	*a*	
Maryland	○	. . . . .	. . . .	. . . .	. . . . .	—	—	○	—	—	○	—	—	○	. .	18	21	. .	25		
Massachusetts	—	½	60	—	○	11	—	○	—	—	○	—	—	*c*	—	10	13	○			
Michigan	*a*	⅜	0	○	○	*c*	—	○	*c*	—	¼″ in 10′	*b*	—	—	14	18	21	○			
Minnesota	*b*	○	0	○	○	—	○	○	—	—	¼″ in 10′	—	—	—	10	○	21	—	27	—	2–3
Mississippi																					

Missouri	–	¼	36	○	○	–	○	○	–	○	14″	–	–	○	14	0	0	*b*	25	○	2–3
Montana	–	⅜	30	○	○	–	–	–	Belt	–	¼″ in 10′	–	–	–	10	20	30	*b*			
Nebraska	×	.....	....	○	–	*c*	○	○	*c*	–	¼″ in 10′	–	–	–	10	○	28	*b-a*			
Nevada	–	½	34	○	○	–	○	○	–	○	○	–	○	–	12	○	21	○			
New Hampshire	–	¼–½	40	○	○	11	–	○	–	○	○	–	–	○	○	18	21	*b*	25	○	2
New Jersey	–	½–¾	50–85	*b*	Longitudinal	11	–	*b*	–	–	¼′ in 10′	–	–	○	10	○	14	*a*	65–90	*a*	
New Mexico	–	¼–½	30	○	○	11	–	○	–	○	○	–	–	○	18	18	21	*b*	25	○	2
New York	–	½″ per 100 ft.	**300	○	○	–	○	○	–	–	½″ in 10′	–	–	–	8	14	14	*a*	25–110	–	○
North Carolina	At stop	½–1	At stop	○	–	22	○	○	–	–	○	–	–	–	14	21	21	*b*	*a*	*a*	2
North Dakota																					
Ohio	Under 50°F.	¼	50	○	○	–	–	○	–	1½ mile or more	¼″ in 10′	–	–	–	10	○	21	*b*	56	–	2
Oklahoma	–	½	40	○	–	11	–	○	–	○	○	–	–	○	○	18	21	○			
Oregon	–	⅜	30	*b*	Longitudinal	–	–	–	Roller	○	○	–	–	–	10	21	28	*b*	*a*	*a*	*a*
Pennsylvania	*a*	½	*a*	*b*	○	8	○	○	–	–	¼″ in 8′	–	–	○	8	18	21	*b*	65	–	2
Rhode Island	–	¼	*a*	–	–	22	–	○	–	○	○	–	–	○	○	18	21	–	○	–	*a*
South Carolina	–	¼–½	40	○	○	8	–	○	–	○	¼″ in 9′	–	–	○	10	18	18	*b*	25	○	2
South Dakota																					
Tennessee																					
Texas	*a*	¼–½	*a*	○	○	8	–	○	–	–	.....	–	–	–	14	14	20	–	25	○	2
Utah	–	¼–½	40	Over 27′ wide	○	–	○	○	–	○	○	–	○	–	10	○	20	*a*	–	–	2
Vermont	–	½	30–50	○	○	–	○	–	–	–	○	○	–	○	–	18	21	–	40	–	2
Virginia	–	¼–½	*a*	○	○	11	–	○	–	○	○	–	–	*c*	*b*	18	21	*a*	40	○	2
Washington	–	⅜–½	30	○	○	–	–	–	Roller	○	○	–	–	–	10	14	30	*b*	28	–	2
West Virginia	*b*	¼–⅜	○	○	○	–	–	○	–	–	○	○	–	○	10	10	13	*b*	–	–	2
Wisconsin	–	¼–⅜	50	○	○	–	–	–	–	○	¼″ in 10′	–	–	–	14	18	21	*a*			
Wyoming																					

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b Where required.
c With special permission.
– Required or allowed.
× Specifically prohibited.
○ Not required or not mentioned.
* 1:2:4 when machine finished.
** Expansion joints at noon, night and ends of vertical and horizontal curves.
† Central mixing plants and chute mixers prohibited.
Expansion joints omitted in July and August.

that the 1.90 factor could have been easily maintained and there would have been no overrun of Cement on the Contract.

My original instructions to you in this matter of batching were officially overruled by the Department on the ground that they did not exactly comply with the Specifications and we were both instructed to batch 3 bags of cement, 4.28 cu. ft. of sand and 8.56 cu. ft. of stone. This ruling raises the Cement factor about 5 per cent and under this ruling I am willing and justified in certifying a maximum of 2.02 bbl. per cubic yard where this amount is actually used. This will involve a possible overrun on the Contract of about 750 bbl. of Cement (Item 17) and there is no question in my mind but what this overrun should be approved under the batching instruction we have received.

Up to date however you have used 2.10 bbl. per cubic yard of pavement and this amount is excessive and not warranted. It is apparently due to a shortage of stone and sand in the mix. Between sta. 157 + 86 and 121 + 68 you used 2,110,000 lb. of stone (Railroad weights) and 2,246.50 bbl. of cement. On the basis of batching 3 bags of cement, 4.28 cu. ft. of sand and 8.56 cu. ft. of stone you should use at least 990 lb. of stone per bbl. of cement. (Inequality of grade has no effect on this basis of figuring.) Between these stations you should have used at least 2,224,000 lb. of stone, showing a shortage of 114,000 lb. or 5 per cent of the total. Stone amounts to about 80 per cent of the compacted concrete and a shortage of 5 per cent would raise the cement factor about 4 per cent. The average cement factor between these stations was 2.09 or 3½ per cent above the amount I am willing to certify.

In a similar manner between sta. 157 + 86 and 128 + 15 you used 979,800 lb. of sand and 1,860 bbl. of cement. You should have used at least 1,090,000 lb. of sand showing a shortage of approximately 10 per cent. Sand amounts to about 40 per cent of the pavement volume and a 10 per cent shortage would account for a 4 per cent increase in the cement factor which checks the stone results given above.

Your batching apparatus consisting of steel sand hoppers and a steel double gate Blaw Stone batcher has been rated by me and found to be correct. The exactness of your routine batching however depends on the care of your men and I have personally noted a number of cases where under stress of time they were not completely filled. As a further evidence of carelessness in batching your daily cement factor has ranged from 1.92 to 2.20. The grade work has been excellent and while minor inequalities in grade which it is impossible to prevent might account for a small variation they would not account for such a big range.

The outstanding facts are that you have not used enough sand and stone and that it is evident that more care is necessary to prevent overrun in measuring your sand and stone. It is not the function of the Engineer or Inspectors to act as foreman for your men and prevent careless work. Our duty lies in calling your attention to conditions and in stating the maximum limits of variation that we are willing to accept. We shall be pleased to give you a daily statement of the Cement Factor but will hold you responsible for variations which exceed the ruling given in the first of this letter.

Sincerely yours,
Engineer in Charge.

General Maintenance Methods.—Detail maintenance is discussed in Chap. IV, page 444. Concrete pavement maintenance consists in the repair of cracks and joints and the renewal of shoulders. On rural roads cracks and joints are generally sealed with bitumen or a mixture of bitumen and sand. On village pavements cracks and joints are generally filled with resinous compounds of approximately the same color as the concrete. Holes in the concrete or badly depressed corner breaks are temporarily filled with cold patch and repaired as soon as possible by cutting out a fair sized area and replacing the concrete. On lighter travelled roads, shoulders are renewed by scraping additional earth up along the edge with a road machine; on heavy traffic roads they are built up by the use of gravel, macadam or cold patch.

ASPHALTIC CONCRETE PAVEMENTS

Ordinary asphalt surfaces are probably familiar to most readers. Asphaltic concrete surfaces are merely a well-graded mineral aggregate mixed and cemented with bitumen. This general type includes Sheet Asphalt, Topeka Mix, Warren Bros. Bitulithic, Amiesite, Bito. Slag and various other trade name products. These surfaces are laid on either macadam or cement concrete bases. Specifications, page 328, describe construction operations in detail.

FIG. 133.—New York State main road asphaltic concrete (modified Topeka) on concrete base 17 ft. wide with macadam shoulders 6 ft. wide carries daily traffic of 5,000 mixed vehicles (10-hr. count). Serves very satisfactorily except for width. Pavement proper will be widened this season under reconstruction program.

Asphaltic concrete surfaces are satisfactory and economical for the heavier traffic Class I rural roads having a traffic volume of over 3,000 vehicles daily (10-hour count) and for resurfacing of any road carrying over 1,500 to 2,000 vehicles daily. The essential advantage of this type lies in its pleasing appearance, ease of construction and repair and resilient quality which makes it particularly resistant to traffic damage of a large volume of mixed traffic. The high cost of this surface eliminates its use on unimportant roads.

It has been extensively used for resident city streets and a considerable mileage has been constructed on primary state system rural highways. In damp weather, it is often quite slippery for high speed rural traffic, which is a drawback, but it is at present (1922) the most available type for resurfacing wornout rigid pavements and for capping old solid macadam

bases on Class I and IIA roads and it is certain that a considerable yardage of this type will be constructed on rural highways particularly under reconstruction programs. Scientific grading of aggregates and care in construction does much to reduce the faults of waving and extreme slipperiness although these fundamental faults are difficult to prevent entirely.

Asphaltic concrete pavements including concrete or macadam bases cost for initial construction from $3 to $4 per square yard; the yearly maintenance has a wide range but probably falls between $0.004 to $0.035 per square yard for narrow rural highways. The cost of surface renewal

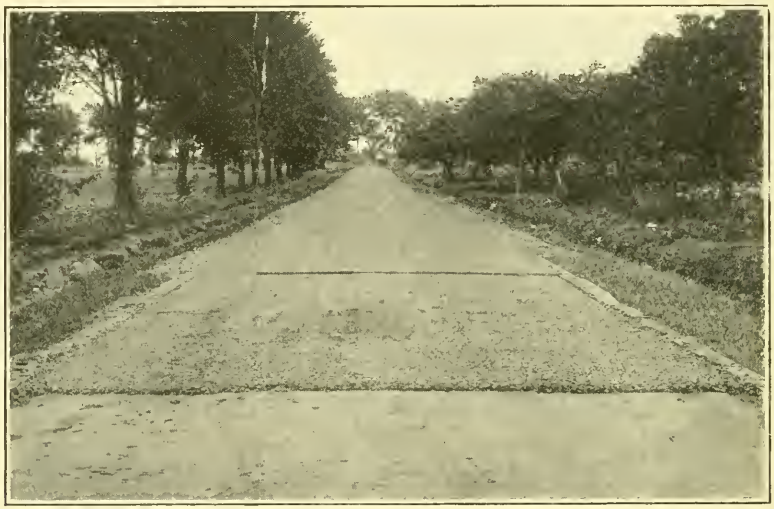


FIG. 134.—Amiesite surface on old worn out cement concrete pavement. Note new stone shoulder along edge of asphaltic concrete surface.

distributed over the life of the surface probably is about $0.08 to $0.15 per square yard per year on narrow rural highway pavements (1922 cost conditions where the traffic volume is more than 3,000 daily).[1]

As this type is expensive and is usually considered only for important roads, the best possible materials should be used. The strength (depth of base) should be amply strong when first constructed as this type of pavement cannot be as easily strengthened by future work as either the macadam or plain concrete type. Materials, Details of Design and Inspection follow the summary of Recommended Designs.

The proper grading of aggregate is a complicated study and the reader is referred to books by Richardson, Hubbard, etc. for complete data. Specifications, page 328, show usual practice for rural highway pavements. The present tendency lies towards the use of increasing percent-

[1] Renewal costs based on maximum allowable Vialog coefficient of 250 without excessive maintenance (see page 150).

age of larger stone fragments under moderate traffic volume to reduce slipperiness and the formation of waves. Under extremely heavy traffic, a fine aggregate is desirable to prevent pitting of the surface. A conservative estimate of surface life for this type on heavy traffic rural roads is about 10 to 15 years although there are many cases which do not fall within these limits (see Chap. IV).

Recommended Designs.—The recommended designs represent conservative practice. It is undesirable to reduce the thickness of base below the depths shown as this type of pavement cannot be easily strengthened by future resurfacings. These designs are based on maximum gross vehicle load of 28,000 lb.

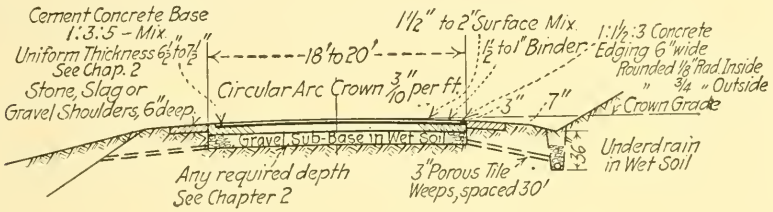


FIG. 135.—Recommended design Class I traffic.

Suitability of Materials. Macadam Bases.—See Water-bound and Bituminous Macadam Pavements, pages 207 and 232.

Concrete Bases.

Cement.—Same as for concrete pavements, page 257.

Coarse Aggregate. (Paving Base).—Any clean hard well-graded size of crushed stone, gravel, or 1,800 lb. per cubic yard crushed slag. Pit run gravel or crusher run stone should not be used; the sizing for coarse aggregate is generally specified as between ¾ to 3½ in. with not over 15 per cent of material passing the 1¼-in. screen. The high standards set for concrete pavement need not be attained as the base is not subjected to traffic pounding. It must produce a strong concrete; it is desirable to use the best available source without raising the cost needlessly; in the main, a local supply should be preferred even if the coefficient of hardness drops as low as 5 for stone or this equivalent for gravel. Shale gravel should not be used but a small percentage of shale up to 10 per cent is allowable. The coarse aggregate must, however, be free from organic impurities and from a coating of clay or loam.

Sand. (Paving Base).—Same general requirements as for concrete pavements except that an 8 per cent maximum loam content can be used with safety (see Specifications, page 550).

Binder and Surface Mix.—The following material from the Asphalt Association Handbook is as authoritative as any available data.

Coarse Aggregate.—Broken Stone Specifications.

FOR ASPHALTIC CONCRETE
(Coarse Graded Aggregate Type)

	Per cent passing screen			
Size	1¼″	¾″	½″	¼″
Coarse aggregate	95–100	25–75	.....	0
Cover for seal coat	.....	.....	95–100	0–15

Per cent of wear ..... 5 per cent

FOR ASPHALTIC CONCRETE
(Fine Graded Aggregate Type)

	Per cent passing screen		
Coarse aggregate,	¾″	½″	¼″
Alternates I	...	95–100	0–75
Alternates II	100	.....	0–75

FOR BINDER COURSE

	Per Cent
Passing 1¼-in. screen	95–100
Passing ¾-in. screen	25– 75
Passing ¼-in. screen	0– 10
Per cent of wear	6

FOR TWO-COURSE ASPHALT MACADAM BASE

	Per cent passing screen				
	3½″	2½″	1¼″	1″	¾″
No. 1 coarse	95–100	0– 15			
No. 2 coarse	.....	95–100	0– 15		
Intermediate	.....	.....	95–100	25–75	0–15

Per cent of wear ..... 8 per cent

FOR ASPHALTIC CONCRETE BASE

	Per cent passing screen				
Coarse aggregate, in...	2½″	1½″	1¼″	¾″	¼″
Alternates I	95–100	.....	25–75	.....	0
Alternates II	.....	95–100	.....	25–75	0

Per cent of wear ..... 5 per cent

Broken Slag[1] Specifications.—Broken slag may be used in place of broken stone for the various types of asphalt pavements and bases the requirements for size being the same as those given under Broken Stone Specifications. In addition the following requirements are commonly made.

Per cent of wear..... 10 per cent −
Weight per cubic foot for each size specified..... 70 lb. +

Gravel[1] Specifications.—Gravel may be used in place of broken stone for coarse graded aggregate asphaltic concrete, binder coarse and asphaltic concrete base with the same requirements for size as those given under Broken Stone Specifications. The gravel should be composed of sound, hard, durable pebbles free from clay or coatings of any character.

Sand or Fine Aggregate Specifications.

Coarse Graded Aggregate Asphaltic Concrete and Asphaltic Concrete Base

Passing	Retained on	Per cent
¼-in. screen	.....	100
¼-in. screen	10-mesh sieve	0–20
10-mesh sieve	40-mesh sieve	15–20
40-mesh sieve	80-mesh sieve	25–60
80-mesh sieve	200-mesh sieve	7–40
200-mesh sieve	.....	0– 6

Fine Graded Aggregate Asphaltic Concrete and Sheet Asphalt

Passing	Retained on	Per cent	
10-mesh	.....	98–100	
10-mesh	20-mesh	3–15	14–50
20-mesh	30-mesh	4–15	
30-mesh	40-mesh	5–25	
40-mesh	50-mesh	5–30	30–60
50-mesh	80-mesh	5–40	
80-mesh	100-mesh	10–20	16–40
100-mesh	200-mesh	6–20	
200-mesh	.....	0–5	

[1] Gravel or slag are not advised where a good grade of stone is available.

The sand shall consist of clean, hard durable grains free from clay, loam and other foreign matter.[1]

Mineral Filler Specifications.—Limestone dust, slate dust or Portland cement.

	Per Cent or More
Passing 30-mesh sieve	100
Passing 200-mesh sieve	60

Bitumen.—Detail specifications for suitable asphalt and tar binders are given on page 551.

A considerable range in the value of penetration depending on climatic and traffic conditions is the only point necessary to indicate at this part of the discussion. The values recommended for asphalt are as follows:

Table 31.—For Asphaltic Concrete

Traffic	Temperature		
	Low	Moderate	High
Light	60–70	60–70	50–60
Moderate	60–70	60–70	50–60
Heavy	50–60	50–60	50–60

Table 32.—For Sheet Asphalt

Traffic	Temperature		
Light	50–60	50–60	40–50
Moderate	50–60	50–60	40–50
Heavy	40–50	40–50	30–40

If a tar binder is used, the usual grade corresponds to Tarvia X (Barrett Company Specifications).

Amounts of Material. *Macadam Bases.*—See Water-bound and Bituminous Macadam Pavements, pages 209 and 234.

[1] Heat from drying drum generally eliminates all organic impurities except free matter like sticks or leaves.

CEMENT CONCRETE BASES PER CUBIC YARD

Mix	Coarse aggregate, cubic yards	Sand, cubic yards	Cement, barrels
1:3 :6	0.95	0.47	1.0
1:2½:5	0.92	0.46	1.2
1:2 :4	0.90	0.45	1.5
1:1½:3	0.84	0.42	1.9

Asphaltic Mixes.—The following data is taken from the Asphalt Association Handbook and applies to unpatented mixtures:

COARSE GRADED AGGREGATE ASPHALTIC CONCRETE
2 In. Thick, Excluding Seal Coat

Materials	Pounds per square yard	Tons per mile 1 ft. wide
Coarse stone	147	43.1
Sand	58	17.0
Mineral filler	9	2.6
Seal coat stone	25	7.3
Asphalt	18	5.3

FINE GRADED AGGREGATE ASPHALTIC CONCRETE (MODIFIED TOPEKA)
2 In. Thick

Materials	Pounds per square yard	Tons per mile 1 ft. wide
Stone chips	53	15.5
Sand	123	36.1
Mineral filler	18	5.3
Asphalt	18	5.3

Amiesite.—This is a patented pavement made of crushed stone coated with asphaltic cement. It has been used on many miles of road with good results. It is shipped cold in a friable and granulated state, spread on either macadam or concrete base and well rolled. Amiesite screenings are then spread and rolled, forming the surface. This construction costs about the same as asphaltic concrete per square yard. It resembles asphalt in appearance and has the advantages and disadvantages of all roads of this class. It is particularly adapted for small jobs where it

would not pay to set up an asphalt plant or where suitable asphalt materials are not locally available.

AMIESITE. TABLE OF DEPTHS AND WEIGHTS—(WEIGHTS GIVEN ARE PER SQUARE YARD)

	Amiesite loose, inches	Weight, pounds	Amiesite square yards per ton	Filler loose, inches	Weight, pounds	Filler square yards per ton	Total depth loose, inches	Total weight, pounds	Ultimate compression, inches	Square yards per ton
Limestone.....	2¼	153	13.0	1	67¾	29.5	3¼	220¾	2	9.06
	2⅝	178½	11.3	1	67¾	29.5	3⅝	246¼	2¼	8.12
	3	204	9.8	1	67¾	29.5	4	271¾	2½	7.36
	3⅜	229½	8.7	1	67¾	29.5	4⅜	297¼	2¾	6.73
	3¾	255	7.8	1	67¾	29.5	4¾	322¾	3	6.20
Trap rock.....	2¼	168¾	11.8	1	75	26.6	3¼	243¾	2	8.20
	2⅝	196⅞	10.2	1	75	26.6	3⅝	271⅞	2¼	7.36
	3	225	8.9	1	75	26.6	4	300	2½	6.66
	3⅜	253⅛	7.9	1	75	26.6	4⅜	328⅛	2¾	6.10
	3¾	281¼	7.1	1	75	26.6	4¾	356¼	3	5.60
Sandstone.....	2¼	164¼	12.2	1	73	27.4	3¼	237¼	2	8.43
	2⅝	191⅝	10.4	1	73	27.4	3⅝	264⅝	2¼	7.56
	3	219	9.1	1	73	27.4	4	292	2½	6.85
	3⅜	246⅜	8.1	1	73	27.4	4⅜	319⅜	2¾	6.26
	3¾	273¾	7.3	1	73	27.4	4¾	346¾	3	5.77

To find the amount of loose Amiesite necessary for any compressed thickness, subtract ½ in. from compressed thickness, multiply by 1½ which equals loose thickness, to which add 1 in. for filler.

To find what compressed thickness any given amount of loose Amiesite will give, subtract 1 in. from loose thickness, multiply by ⅔ and add ½ in. for filler.

Design.—Design includes decisions in regard to the selection of either macadam or cement concrete as the base; the depths of base required for the soil and traffic conditions prevailing; the width and crown of the pavement and the mix and depth of the asphaltic concrete surface.

Type of Base.—Macadam base is an economical design for moderate traffic where the macadam is constructed at least a year ahead of the asphalt surface. Macadam bases are rarely desirable where the asphaltic surface is laid on newly constructed macadam as traffic pounding is necessary to compact macadam construction properly.

Cement concrete base is the most feasible type for heavy traffic where it is desirable to get quick results on new grading but should be used with caution on new fills of depths of over 2 to 3 ft. unless special care is taken in grading operations. Despite all care, it is not advisable to use concrete base on fills over 10 ft. high or on side hill sections part in cut and part in fill unless the grading is at least 1 year and preferably 2 years old.

Depth of Base.—If the macadam type of base is selected, it is merely a matter of macadam design. The required depths and the most economical

use of local materials were discussed under macadam design and the reader is referred to Chap. II, pages 99 to 100 and Macadam Pavements, pages 203 to 238.

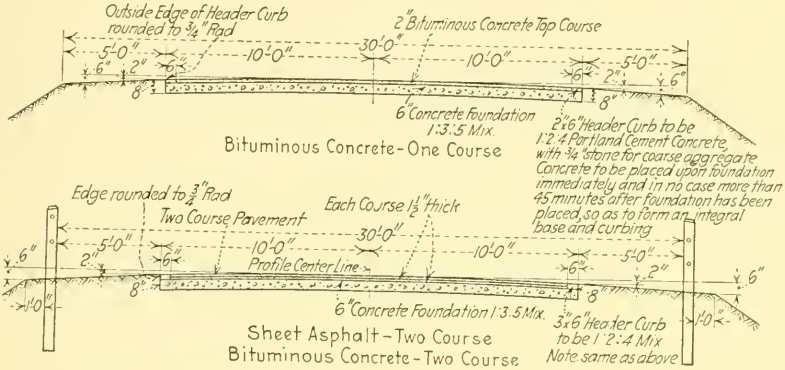

Outside Edge of Header Curb rounded to ¾" Rad
2" Bituminous Concrete Top Course
6" Concrete Foundation 1:3:5 Mix.
Bituminous Concrete - One Course
2'6" Header Curb to be 1:2:4 Portland Cement Concrete with ¾" stone for coarse aggregate Concrete to be placed upon foundation immediately and in no case more than 45 minutes after foundation has been placed, so as to form an integral base and curbing
Edge rounded to ¾" Rad
Two Course Pavement
Each Course 1½" thick
Profile Center Line
6" Concrete Foundation 1:3.5 Mix.
Sheet Asphalt - Two Course
Bituminous Concrete - Two Course
3'6" Header Curb to be 1:2:4 Mix
Note same as above

FIG. 136*A*.—Standard bituminous concrete, State of New Jersey (1922).

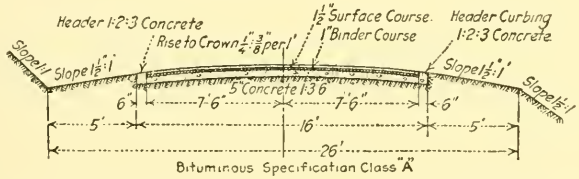


FIG. 136*B*.—Standard section, State of Pennsylvania (1922).

CONTRACTION AND EXPANSION OF MORTAR AND CONCRETE

Mortars		Concretes	
Mixture	Coefficient of expansion per degree Fahrenheit	Mixture	Coefficient of expansion per degree Fahrenheit
Neat	0.000,007,83	1:1½:3	0.000,006,77
1:1	0.000,007,43	1:2 :4	0.000,006,60
1:2	0.000,006,00	1:2½:5	0.000,005,58
1:3	0.000,006,05	1:3 :6	0.000,005,37
1:4	0.000,005,94		
1:5	0.000,005,77		

If the concrete type of base is selected, it is necessary to decide on the richness of the mix and the depth of base. Engineers differ as to the desirability of the different mixes which range in common practice from 1:3:6 to 1:2:4. For the same strength, the leaner mixes require

greater depth and they are also a little more apt to be porous and to break down over trenches but transverse contraction cracks seem less noticeable with the leaner mixtures probably on account of lower coefficient of expansion and contraction. The tendency is towards the use of 1:2½ :5 or 1:3:5 as a good practical mix. The depths of base recommended for different mixes under different traffic loading is given in Table 23, page 137, and ranges from 6 to 8 in.

Surface Mix.—The surface mix is generally in two layers, binder and finer aggregate mix. The depths range from 2 in. where binder is not used to 3 in. for the heavier traffic streets (1-in. to 1½-in. binder and 1½ to 2-in. fine aggregate top).

Figures 135 and 136 show the depths of binder and fine mix in common use (1922) on rural highways. Personally the author prefers 1-in. closed binder and 1½-in. Modified Topeka Surface Mix for ordinary highway work. On extremely heavy traffic road, a 1½-in. binder with 1½ in. of Fine Graded Mix is probably better for such conditions. There is an infinite variety of mixes depending on materials available and local climatic and traffic conditions and the best mix to adopt is largely a local problem which can be best solved by an expert asphalt man and gradually modified by observed action for any locality. Practically all authorities are agreed that the most common serious fault of surface mixes lies in insufficient fine sand passing 80 and retained on 200; insufficient or poor grade filler passing 200 and a poor relation between the proportions of fine sand 80 to 200 to the amount of filler and bitumen. *The lack of durability of many pavements is directly chargeable to carelessness in grading.* The following typical mixes are recommended by the Asphalt Association and should serve very satisfactorily in case local practice has not crystalized on a somewhat different mix. The reader is referred to books by Clifford Richardson, Prevost Hubbard, etc., for detail data on asphalt mixtures.[1]

TYPICAL MIXES RECOMMENDED BY ASPHALT ASSOCIATION

Asphaltic Concrete Surface Course (Fine Graded Aggregate Type)

Thickness, 2 in.
Crown, ⅜ in. to the foot recommended.
Materials—See preceding discussion.
Mixture

	Per Cent
Passing ½-in. screen, retained on 10-mesh	20.0 to 35.0
Passing 10-mesh sieve, retained on 40-mesh	7.0 to 25.0
Passing 40-mesh sieve, retained on 80-mesh	11.0 to 36.0
Passing 80-mesh sieve, retained on 200-mesh	10.0 to 25.0
Passing 200-mesh sieve	7.0 to 11.0
Bitumen (asphalt cement soluble in carbon disulphide)	7.5 to 9.5

[1] See Richardson, "Asphalt Construction," McGraw-Hill Book Co., page 70.

Sheet Asphalt Binder and Surface Courses

Thickness, Binder course 1½ in. recommended.
Wearing course 1½ in. recommended.

Total..... 3 in.

Crown, ¼ in. to the foot recommended.
Materials—See preceding discussion.
Mixtures

	Per Cent
Binder Course	
Coarse aggregate retained on 10-mesh sieve	60.0 to 80.0
Sand and material passing 10-mesh sieve	15.0 to 35.0
Bitumen (asphalt cement soluble in carbon disulphide)	4.0 to 6.0
Surface Course	
Passing 10-mesh, retained on 40-mesh sieve	10.0 to 40.0
Passing 40-mesh, retained on 80-mesh sieve	22.0 to 45.0
Passing 80-mesh, retained on 200-mesh sieve	12.0 to 30.0
Passing 200-mesh sieve	10.0 to 20.0
Bitumen (asphalt cement soluble in carbon disulphide)	9.5 to 12.0

Probably the simplest way for the student to consider an asphalt mixture is in two steps. First the asphaltic mortar composed of bitumen and all the mineral aggregate passing a No. 10 sieve and second the coarse mineral aggregate retained on the No. 10 sieve. The mortar must conform to the requirements of a good sheet asphalt, all ingredients of which pass a No. 10 sieve, and the amount of coarse aggregate added to the mortar has no effect on proportioning the mineral aggregate of the mortar although it does have some effect on the total bitumen in the final mix.

Good representative ideal mortar mixes used in northern states for different volumes of traffic are shown in table on page 310.

It is important to have from 10 to 12 per cent of bitumen to insure good life, waterproofing, etc., but in order to carry the proper amount of bitumen and still have a good workable and stable mix the proportion of bitumen, 200 and 80 factors must be about as shown. A good grade of filler (200 sieve) is important. Limestone dust or Portland cement make the best and most dense product but it is rarely advisable to entirely eliminate the 200-mesh sand content although it is probably justifiable to restrict the 200-mesh sand to a maximum of 5 per cent of mortar mix and make up the balance with the cement or stone dust filler.

The second factor (coarse stone aggregate $\frac{1}{10}$ to ½ in. in size) is added to increase stability of mix under traffic, to decrease slipperyness of the pavement and to reduce the cost of the mix. For the ordinary so called modified Topeka which is a popular type the amount of coarse stone used ranges from 15 to 30 lb. per 100 lb. of total surface mixture.

This coarse aggregate consists of the stone coated with bitumen. The amount of bitumen necessary to coat the stone of the size usually used is about 2 per cent of the weight of the stone.

The final proportions of a mix consisting of both mortar and coarse aggregate can now be very easily computed. Suppose we propose to figure an ideal mix using 20 lb. of coarse aggregate and 80 lb. of mortar

Asphaltic Mortar Mix (Percentages by Weight)

Class of traffic	Bitumen, per cent	Mineral aggregate				Total all factors, per cent
		200 sieve	80	40	10	
Light	10.0	10.0	15	30	35	100
Medium	10.5	12.5	18	34	25	100
Heavy	11.0	15	21	34	19	100
Allowable variation (per cent each size or factor)	9.5 to 12	10 to 20	12 to 30	22 to 45 This column should not be much over twice the 80 column	10 to 40 This column not as important	
	The relation of these columns must remain about constant. That is they must all rise or fall together					

making 100 lb. of completed surface mix. The amount of each factor in the mortar content of the final mix is obtained by multiplying the percentages given in the preceding table by 80 lb. The amount of bitumen figured for the mortar is then increased by 2 per cent of the weight of the coarse aggregate 20 lb. $\times$ 00.2 = 0.4 lb. and the net weight of the coarse aggregate is added as a new factor. The table on page 311 of ideal mix for Topeka construction is computed in this manner.

Binder.—The binder course may be either of the so-called "open" or "closed" types. Open binder is merely asphalt or tar coated stone ranging in size from $\frac{5}{8}$ to $1\frac{1}{4}$ in. This type of binder requires from 3.5 to 4.5 per cent of bitumen. The closed binder is more nearly a true asphaltic concrete and requires careful grading of aggregate. By courtesy of Clifford Richardson we quote from his book on Asphalt Construction.[1]

[1] "Asphalt Construction," McGraw-Hill Book Co.

Open Binder.—Open binder consists of stones largely of one size, the fragments being from ¾ to 1 in. in their largest diameter, although at times run of crusher has been used. Broken stone of the latter description requires a larger amount of bituminous cementing material, and in consequence the binder is more cohesive. The following data will show the average composition of open binders which have been used at different times in the construction of sheet asphalt pavements.

It appears from these figures that the percentage of bitumen which a binder requires depends largely upon the amount of fine material which it contains. The first mentioned in the table contains 26.8 per cent of fine material and

TABLE OF IDEAL PROPORTIONS, MODIFIED TOPEKA MIX

Surface Mix (Percentages of Complete Mix by Weight)

Class of traffic	Bitumen	Mineral aggregate						Total, all factors
		200 sieve	80	40	10	¼ in.	½ in.	
Light	8.2	7.0	12	22	26	17	8	100
Medium	8.8	9.2	14	25	21	15	7	100
Heavy	9.5	11.5	17	28	16	13	5	100
Allowable variation (per cent for each size or factor)	8 to 10	7 to 12	10 to 25	11 to 36	7 to 25	10 to 20	Less than 10	

requires 5.4 per cent of bitumen, while those made from cleaner stone where the fine particles do not exceed 5 per cent, contain less than 4 per cent of bitumen. In preparing, sending to the street, and placing a course of open binder, care is demanded in certain directions. The stone should be hard, sufficiently so not to crush under the roller. It should be free from clay and dirt, although as has been said, fine particles of the stone itself are an advantage rather than otherwise. In heating the stone and mixing it with the asphalt cement, great care should be used that it is not overheated, since if this is the case a proper coating of the bonding material will not adhere to the stone, owing to the excessive heat, or much of it may run off and be lost during the haul to the street. On the other hand, the binder should be hot enough to permit of properly coating it and its ready compression on the foundation. An open binder should be bright and glossy, and not dead in appearance, as it is dumped from the truck. It should be hot enough to spread readily and uniformly. It should contain no excess of bitumen at any one spot, and should this be the case, such spots should be removed and replaced. Binder after it has been placed on the street or road, should be covered within the shortest space of time possible with the surface, as when it has been wet, tracked with dirt, or become covered with horse-droppings or dead leaves, the adhesion of the surface mixture to it will not be complete.

In actual practice a 9 cu. ft. box of broken stone for binder which will weigh about 900 lb. will require about 40 lb. of Trinidad and about 36 lb. of Bermudez asphalt cement, but the cement must be regulated by observing the appearance of the material in the truck and on the street.

In preparing a binder at the plant the mixer in use should have teeth with a sufficient clearance between them and the lining of the mixer so that the largest particles of stone cannot become wedged between them, and thus rapidly wear out the lining of the mixer. It is not good practice to attempt to mix binder in the same mixer that is employed for preparing the surface mixture. A separate one should be employed, although in some of the smaller plants of a portable description, it is not always possible to do so, in which case provision must be

Average Composition of Open Binders Used in Sheet Asphalt Pavement

Test No.	69978		70804		70854		71102		74893	
Bitumen	5.4%		4.4%		3.8%		3.6%		3.5%	
Filler	5.8	26.8	4.1	16.6	2.2	9.7	2.4	5.4	1.5	4.5
Sand	21.0		12.5		7.5		3.0		3.0	
Stone:										
Passing ¼-in. sieve	5.8		8.7		18.0		13.5		49.5	
Passing ½-in. sieve	13.6	67.8	46.8	79.0	52.0	86.5	51.5	91.0	10.0	92.0
Passing 1-in. sieve	41.4		23.5		16.5		26.0		32.5	
Retained 1-in. sieve	7.0		0.0		0.0		0.0		0.0	
	100.0		100.0		100.0		100.0		100.0	

made for making a change of teeth from the longer to a shorter form, in changing from surface to binder mixing.

Close Binder.[1]—Close binder is, or should be, a true asphaltic concrete. It consists of the same broken stone of which the open binder is made, but the voids in it are filled with smaller stone and with an asphaltic mortar corresponding to the ordinary asphalt surface mixture. For the construction of a close binder or asphaltic concrete of the highest type, the grading of the mineral aggregate should be carefully regulated. This can be done by determining the voids in the coarser stone, calculating the amount of fine stone necessary to fill these, and again the amount of sand to fill those in the mixture of coarse and fine stone. This can be readily done by constructing a box of sheet-iron or wood of exactly 1 cu. ft. capacity. It is filled with the hot coarse stone which is compacted by shaking. The surface is then struck off and the box weighed. Allowing for tare, the weight of 1 cu. ft. of the coarse stone is obtained. Knowing the density of this stone, 2.65 for limestone and 2.9 to 3.0 for trap-rock, the weight of a solid cubic foot of the stone can be calculated. By dividing the weight of a cubic foot of the broken stone by the weight of a solid cubic foot of the material, the voids can be determined. In the same way the weight of a cubic foot of the finer stone and of the sand can be arrived at. One can readily calculate the amount of each which it is necessary to use to fill the voids in the coarse stone, and again in the mixture of the coarse and fine stone. The proportions for actual use can be readily determined and the amount of bitumen required from the percentages of broken stone and sand that are present.

[1] Quoted from "Asphalt Construction," Clifford Richardson, McGraw-Hill Book Co.

As an example of the proportions of coarse stone, fine stone, sand and asphalt cement in actual use in preparing a close binder, the following figures will serve:

	New York		Boston
	Plant 1	Plant 2	
Coarse stone	480 lb. = 54.6%	480 lb. = 53.3%	
Fine stone	200 lb. = 22.7	202 lb. = 22.4	885 lb. = 73.4%
Sand	150 lb. = 17.0	150 lb. = 16.7	250 lb. = 20.8
Trinidad asphalt cement		68 lb. = 7.6	70 lb. = 5.8
Bermudez asphalt cement	50 lb. = 5.7		
	880 lb. = 100.0	900 lb. = 100.0	1,205 lb. = 100.0

ANALYSES

Bitumen soluble in CS_2	5.6%		5.2%		4.8%	
Passing 200-mesh screen	4.4		6.4		4.2	
Passing 10-mesh screen	29.2	33.6	29.0	35.4	26.4	30.6
Passing 8-mesh screen	1.8		2.0		0.8	
Passing ¼-in. screen	10.0		7.0		4.4	
Passing ½-in. screen	23.2		25.8		24.4	
Passing ¾-in. screen	13.6		17.8		32.2	
Passing 1-in. screen	7.4		6.8		2.8	
Retained 1-in. screen	4.8		0.0		0.0	
	100.0		100.0		100.0	

At some plants it is impossible to separate the stone into coarse and fine particles, in which case the heated stone of both sizes is collected in one bin, but segregation generally occurs under such circumstances. In arranging the grading of the mineral aggregate care should be taken to see that the amount of fine material, while sufficient to fill the voids in the stone, is not present in excess, since in this case the surface of the binder when compacted on the street will be too smooth to bond properly with the wearing surface, and resulting displacement under travel will be possible. An excess of bitumen must also be avoided for the same reason, and if spots in the binder as laid show anything of this description, the material should be removed.

An entirely satisfactory close binder can be constructed for all but the most trying conditions by the use of selected old surface material, which has been disintegrated and softened by steam, for filling the voids in the ordinary open binder. It is, of course, a matter of great economy to turn out a close binder in this manner. The old surface material having been crushed and softened by dry steam, is added in the mixer to the hot binder stone and, in this manner,

further disintegrated and distributed among the stone. The proper amount of additional asphalt cement is added to coat the stone and enrich the old surface mixture. It does not possess the complete stability of an asphaltic concrete but it is infinitely superior to the ordinary open binder for the construction of an intermediate course.

The asphalt cement in use in binder may well be considerably softer, ten to fifteen points, when it is possible to make it so, than that in use in the sheet asphalt surface.

In the construction of asphalt pavements with an asphaltic concrete binder course, the surface should be applied to it before it has become entirely cold. It is well to run out binder to the street for not more than half of a working day and to cover it with surface during the same day. This is much more important with a close than with an open binder. It is not possible to do satisfactory work where a large area of close binder is laid on one day and covered with surface on the next.

Width and Crown.—Normal widths for heavy traffic roads on which asphaltic concretes can be economically used range from 18 to 20 ft. on straight alignment. On sharp curves, these widths are increased, see Tables 10A and 10B, page 70.

Either the parabolic or circular arc crown is suitable; as discussed under concrete pavements, the circular arc is to be preferred. A crown slope of $\frac{1}{4}$ to $\frac{3}{8}$ in. per foot is usual practice. For rural highways, $\frac{3}{8}$ in. is probably the better rate. For village streets of considerable width, the following figure shows current practice for different types of pavement. As the grade increases the crown is reduced. On sharp curves, a one-way banked crown is used, see page 211 for ordinary practice.

Equipment.—Grading and culvert equipment is similar to any other road job. From the standpoint of the Engineer and Inspector, the essential requirements of the Mixing Plant are described in the pocket reference for Engineers of the Asphalt Association as follows:

Plant Requirements.—(From proposed specifications for sheet asphalt pavements A. S. M. I. 1922.) (*a*) The plant used in manufacturing the pavement must be of the batch type and capable of mixing in the manner herein specified not less than 80 tons of surface mixture per day of 8 hours and must be provided with separate chambers for heating and mixing the ingredients. The stone and sand shall be heated in a suitably designed revolving drier. The mixing shall be done in a twin-shaft mixer of the pugmill type capable of holding and properly mixing not less than a 750-lb. batch of surface mixture. Each plant must be provided with asphalt kettles of such capacity that one filling of them will be sufficient for a day's run and so designed as to secure uniform heating of the entire contents. There shall also be provided a bin for the storage of hot aggregate having a storage capacity of not less than 1 ton and provided with at least two compartments. It shall have an overhead 6- or 8-mesh rotary screen not less than 6 ft. long, for separating the coarse and fine aggregate and delivering them to the separate compartments, also a screen

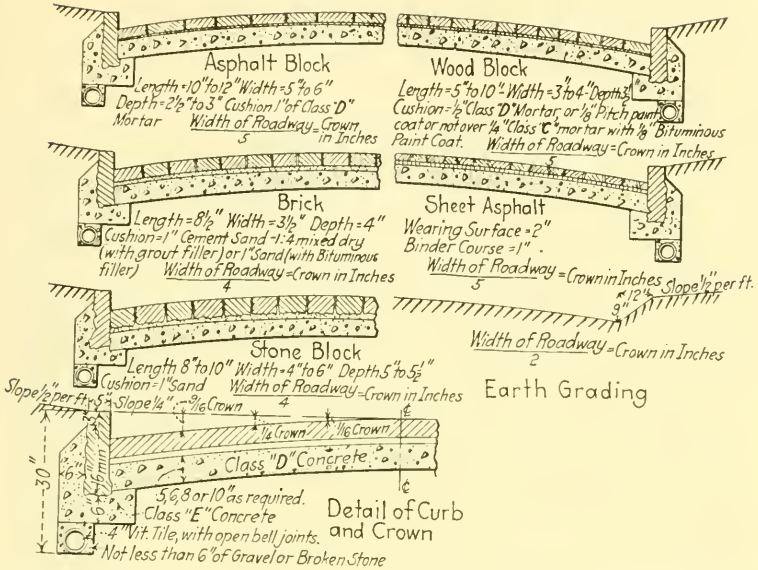

Asphalt Block
Length=10"to12" Width=5"to6"
Depth=2½"to3" Cushion 1"of Class "D" Mortar
Width of Roadway=Crown in Inches / 5
Wood Block
Length=5"to10" Width=3"to4" Depth 3"
Cushion=½"Class "D" Mortar, or ⅛" Pitch paint coat or not over ¼" Class "C" mortar with ⅛" Bituminous Paint Coat.
Width of Roadway=Crown in Inches / 5
Brick
Length=8½" Width=3½" Depth=4"
Cushion=1" Cement Sand 1:4 mixed dry (with grout filler) or 1" Sand (with Bituminous filler)
Width of Roadway=Crown in Inches / 4
Sheet Asphalt
Wearing Surface=2"
Binder Course=1"
Width of Roadway=Crown in Inches / 5
Slope ½" per ft.
12"
9"
Width of Roadway=Crown in Inches / 2
Earth Grading
Stone Block
Length 8"to10" Width=4"to6" Depth 5"to5½"
Cushion=1" Sand
Width of Roadway=Crown in Inches / 4
Slope ½" per ft.
5"
Slope ¼"
⅜ Crown
¼ Crown
⅛ Crown
℄
Class "D" Concrete
30"
5,6,8 or 10" as required.
Class "E" Concrete
4" Vit. Tile, with open bell joints.
Not less than 6" of Gravel or Broken Stone
Detail of Curb and Crown

FIG. 137*A*.—Standard crowns, Rochester, N. Y. *Authors Note*—Rochester crowns give a pleasing appearance.

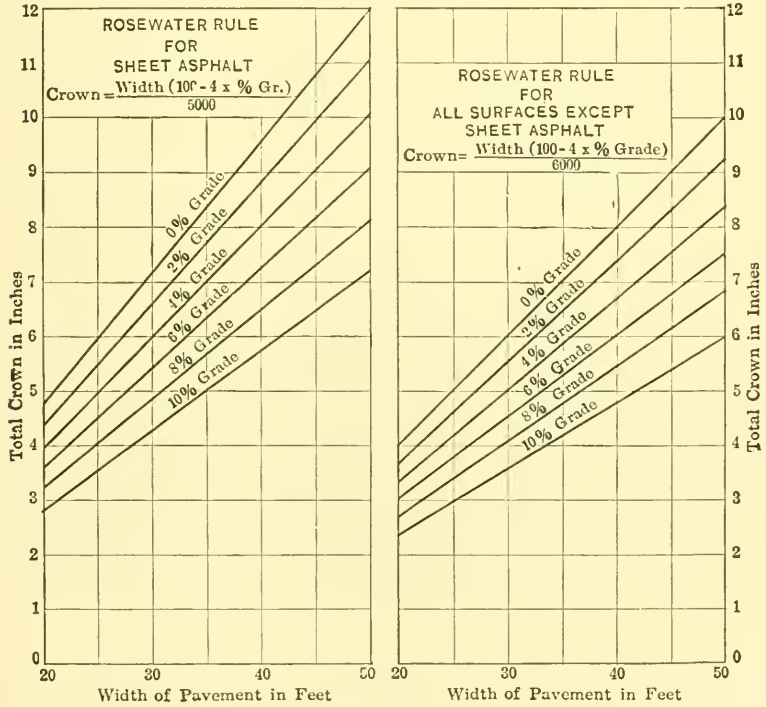


FIG. 137*B*.—City street crowns.[1]

[1] AGG's. "Construction of Roads and Pavements."

for rejecting oversize binder stone; bins and screen to be provided with overflow pipes. (NOTE.—The size opening in the screen should be varied according to the type of mixture as required by specifications.) The hopper into which the hot

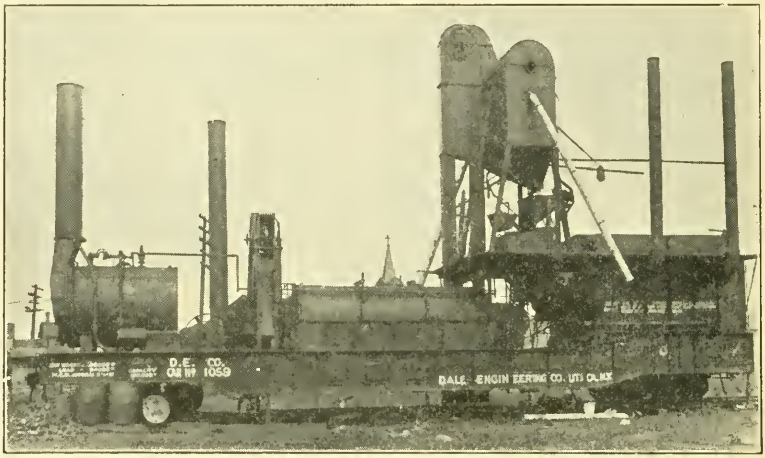


FIG. 138A.—Portable car mixing plant set up ready for operation. Cost $25,000 to $30,000. Capacity 100 to 150 tons daily.

aggregate is drawn from the bin must rest upon a set of scales so arranged that a definite weight of material can be weighed out of the bin and delivered to the mixer.

(*b*) The asphalt bucket used to measure and apply the asphalt must be balanced upon a set of scales and so arranged that the asphalt can be easily and quickly weighed and be applied in a thin sheet the full width of the mixer.

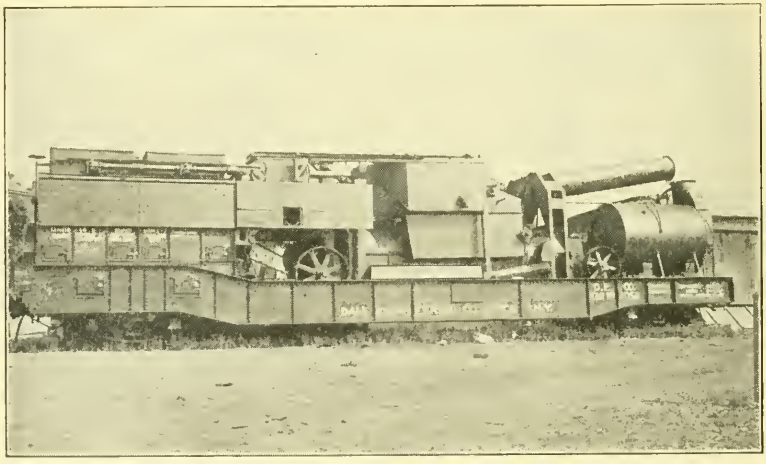


FIG. 138*B*.—Knocked down ready for shipment.

(*c*) The plant shall be provided with an asphalt thermometer for the melting kettles of the recording type where steam heat is not used, an electric pyrometer at the discharge chute of the drier, a platform scale and at least two inspector's armored thermometers.

(*d*) The different kinds of sand and stone used shall be kept separate and such provisions as are deemed necessary by the engineer to keep them from becoming mixed shall be made by the contractor.

Hauling and Laying Equipment.—The hot mix is usually hauled to the road in trucks covered with canvas and the spreading equipment includes suitable rakes, shovels, tampers, tool heaters, brooms, pouring pots and one or two tandem rollers, preferably of two sizes, a 5 ton and an 8 ton.

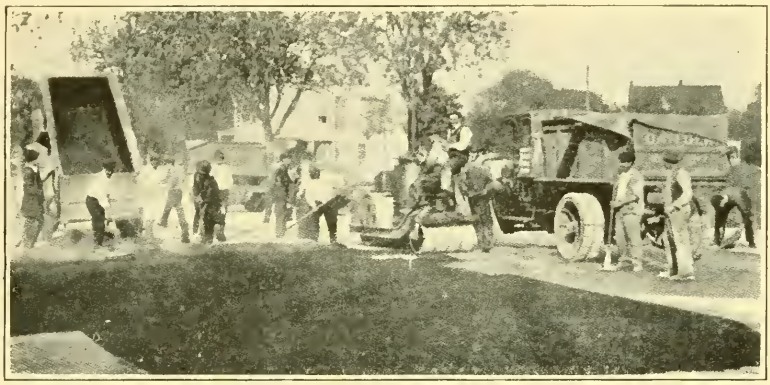


FIG. 139.—Usual laying equipment.

Inspection Details.—Two inspectors are required to handle the plant work and the road work.

Plant Inspection.—Plant inspection covers testing materials and proportions of mix. Checking temperatures, uniform feed of aggregates to drying drum, time of mixing and certification of load weights as the mix leaves the plant for the road.

Plant testing can be carried out with the following equipment:

Plant Testing Equipment.

1 set of standard screens and sieves as may be called for in specifications requirements.

1 stiff brush for cleaning sieves.

1 laboratory stone balance (pan capacity 10 lb.).

1 laboratory sand balance (pan capacity 100 gr.).

1 penetration machine with needles, glass dish large pan for holding water and thermometer.

1 paddle and roll of manilla paper for pat test (for sheet asphalt surface mixtures).

2 armored thermometers of suitable range for recording temperatures of the hot aggregates and mixtures.

A supply of report forms.

All apparatus should be properly housed in a separate building or room not less than 10 by 10 ft. and provided with a stool and work bench.

Sampling should follow the proposed methods of the American Society.

Samples.—(Adapted from proposed specifications for sheet asphalt pavements A. S. M. I. 1922.) Samples should be put in clean, dry containers, preferably tin boxes or cans. The following amounts of the different materials are required for test:

	Pounds
Stone, slag and gravel	5
Filler	½
Sand	1
Refined asphalt	1
Asphalt cement	1
Flux	1

Method of Sampling.—Extreme care should be taken in every case to obtain a sample which is truly representative of the material to be examined. These samples are for the use of the testing laboratory only and should not be used for testing at the plant before submitting them to the laboratory. The particular precautions to be observed in each case are given below.

Stone, Slag or Gravel.—A sufficient number of 5-lb. samples to be taken from different parts of the pile. These should be thoroughly mixed together and reduced by quartering to the desired size.

Filler.—Samples should be taken from several bags and mixed.

Sand.—Samples should be taken from the interior of the pile where the sand is damp. A sufficient number of 1-lb. samples to be taken from different parts of the pile. These should be thoroughly mixed together and reduced by quartering to the desired size.

Refined Asphalt and Asphalt Cement.—(*a*) In barrels: At least one sample should be taken from each batch. It should be taken at sufficient depth below the surface to insure obtaining representative material free from all dirt or other extraneous matter, and at a point not less than four (4) inches distant from the top and sides of the barrel. (*b*) In tank cars: The contents of the tank should be heated until completely liquid throughout. It should then be agitated and thoroughly mixed by means of air or steam, after which the sample shall be taken from the dome in such a manner as to obtain the asphalt from a point at least three (3) feet below the surface. (*c*) In kettles: The contents of the kettles must be completely liquid and thoroughly agitated previous to and during sampling. The sample may be taken from the pipe through which the material is delivered to the mixer by means of a clean dipper.

Flux.—The directions given for sampling refined asphalt and asphalt cement apply to this material except that under ordinary conditions it is not necessary to agitate the contents of the tank-car.

Surface and Binder Mixtures.—Samples should preferably be taken on the street after the mixture has been shoveled and raked. Samples

taken from the plant shall be obtained from the wagons, special care being observed to avoid material from the top of the load or which appears to vary from the average. Samples should be pressed between a sheet of paper and trimmed while hot to a convenient size. This is known as the pat test. The impression left on the paper is a fair guide as to the proper grading of the mix (see Figs. 140*A* to 140*D*).

A description of the Pat Test from Richardson, "Asphalt Construction," is quoted as follows:

"With the first three points arranged in a satisfactory way, the fourth or last point was to decide on how much asphalt cement the mineral aggregate would carry. This has been determined in recent years by the pat test which readily shows whether an excess or deficiency in asphalt cement has been used. This test cannot, in all probability, be improved upon. If each grain of material in the mineral aggregate is coated with asphalt cement and the voids more than filled the excess will be squeezed out in making a pat and stain the paper excessively. If the voids are not filled the only stain upon the paper will be a light one from the cement coating the grains of sand. A perfect mixture will contain just enough cement to fill the voids in the aggregate, stain the paper well but not excessively. The hotter the mixture the more liquid the asphalt cement and the freer the stain. Cold mixtures will give no indication, while the difference in the markings of a fine and coarse sand will be readily learned by experience.

The preceding instructions are satisfactory for turning out a mixture for the conditions ordinarily met with if the available materials admit of following them, or for judging the character of old surfaces when they have been resolved into their constituents by analytical methods.

The pat paper test which is referred to above, is thus described in the author's book, "The Modern Asphalt Pavement."

"A small wooden paddle with a blade 3 to 4 in. wide, 5 or 6 in. long, and ½ in. thick, tapered to an edge at one end and with a convenient handle at the other, is used to take as much of the hot mixture from the wagon as it will hold, being careful to avoid any of the last droppings from the mixer which may not be entirely representative of the average mixture. Samples of mixture should never be taken from the mixer itself, but only from the wagon after mixing is completed.

"In the meantime a piece of brown manila paper with a fairly smooth surface, 10 or 12 in. wide, and torn off at the same length from a roll of this paper, which can be had at any paper warehouse, is creased down the middle and opened out on some very firm and smooth surface of wood, not stone or metal, which would conduct heat too rapidly. The hot mixture is dropped into the paper sideways from the paddle and half of the paper doubled over on it. The mixture is then pressed down flat with a block of wood of convenient size until the surface is flat. It is then struck five or six sharp blows with the block until the pat is about ½ in. thick."

The paper will be found to be stained to a different degree depending upon whether there is a deficiency a proper amount or an excess, present. Examples of such stains are illustrated in the accompanying Figs. A to D.

FIG. 140*A*.—Slight excess of asphalt.

ERRATA

The legends for Figs. 140*A* and 140*C* have been transposed and should read as follows:

FIG. 140*A*.—About right amount of asphalt.
FIG. 140*C*.—Slight excess of asphalt.

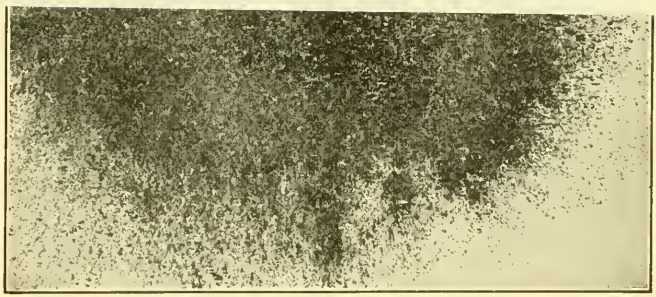


FIG. 140*B*.—Strong excess of asphalt.

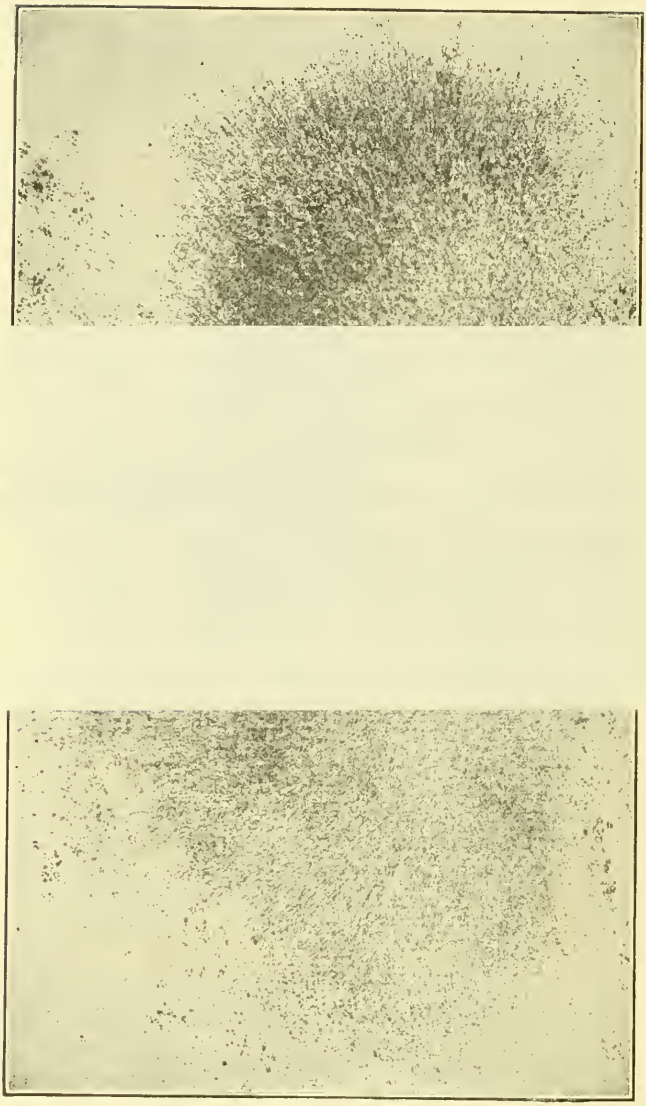


FIG. 140A.—Slight excess of asphalt.

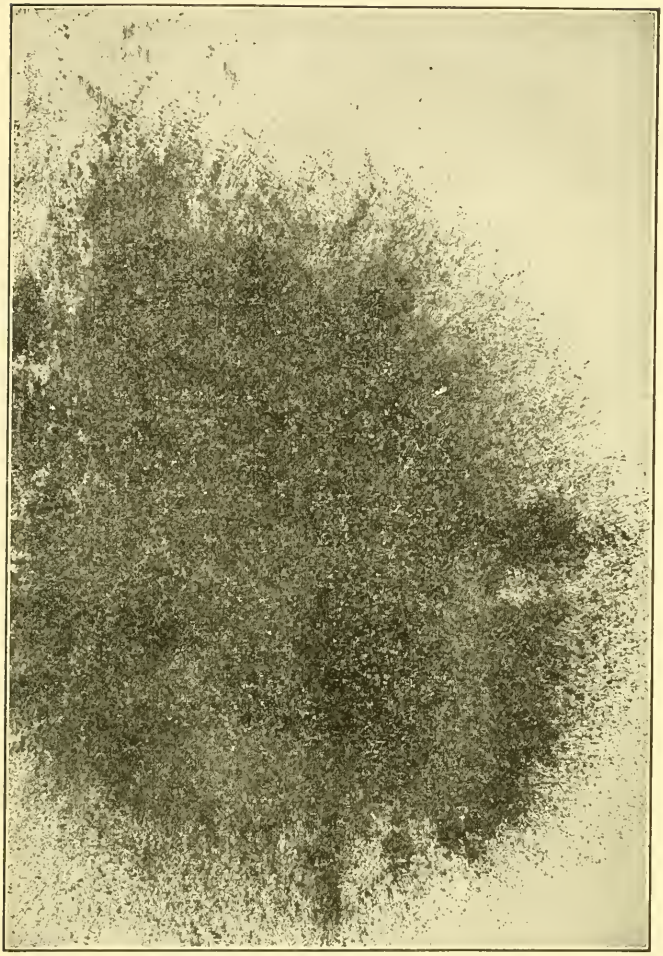


FIG. 140*B*.—Strong excess of asphalt.

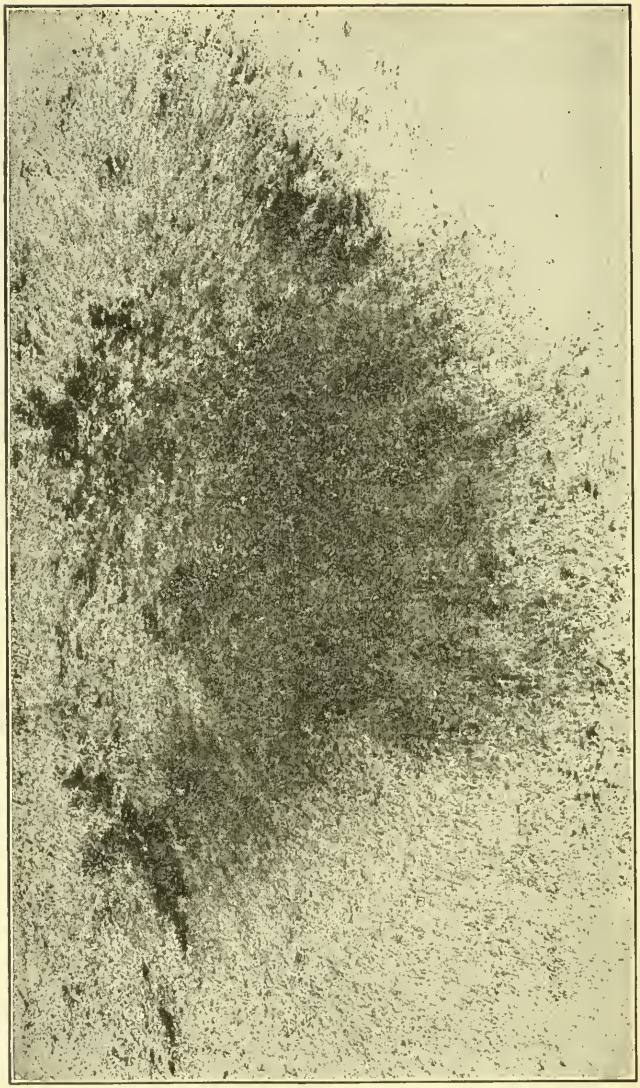


FIG. 140*C*.—About right amount of asphalt.

Plant Analysis.—The proper proportions of aggregate are determined by analyzing the sizing of the different materials separately and then

FIG. 140*D*.—Slightly deficient in asphalt.
FIGS. 140*A*, *B*, *C* and *D*.—Pat test illustrations.
(*From* RICHARDSON'S "*Asphalt Construction for Pavements and Highways*.")

determining the proper proportion of each for the mix desired. A sample record of such work follows:

Proportions of Mix.—The proportions of mix should be determined by the engineer by screen analysis of the different materials that the contractor proposes to use.

As an example assume that a mixture of cement, fine sand, coarse sand and buckwheat stone is proposed and it is desired to determine the relative amounts of the different materials to use in order to get the correct proportion of sizes specified.

For all ordinary purposes a size analysis can be safely made using the following screens: 200, 80, 40, 10, ¼ in. and ½ in.

The materials are thoroughly dried and the percentages expressed by weight.

Fine Sand (Feeder Pit) Road 63

	Per Cent
Passing 200	5
Passing 80 retained on 200	70
Passing 40 retained on 80	25

Good Quality

Coarse Sand (Bauerman Pit) Road 63

	Per Cent
Passing 200	1
Passing 80 retained on 200	2
Passing 40 retained on 80	29
Passing 10 retained on 40	68

Buckwheat Stone (Commercial Plant) Road 63

	Per Cent
Passing 200	1
Passing 40 retained on 200	2
Passing 10 retained on 40	7
Passing ¼ retained on 10	60
Passing ½ retained on ¼	30

The proportions can now be varied to produce practically any required mix.

Tabulation Showing Method of Determining the Number of Pounds of Each Material to be Used in a 100-Lb. Batch to Produce a Required Mix

Material	Number pounds	Bitumen	Mineral aggregate					
			200	80	40	10	¼ in.	½ in.
Bitumen	9.5	9.5						
Cement	8.5	...	8.5					
Fine sand	33.0	...	1.5	23.1	8.4			
Coarse sand	33.0	...	0.3	0.7	9.6	22.4		
Buckwheat stone	16.0	...	0.1	0.1	0.2	1.1	9.7	4.8
Totals	100.0	9.5	10.4	23.9	18.2	23.5	9.7	4.8

Note.—The above mix used on Road 63 has served well for 12 years under class IIA traffic.

In this way the effect of varying any of the component parts of the mix can be readily seen and determined.

The total size of the batch is of course varied to suit the capacity of the plant.

The laboratory analysis of the daily sample taken on the road furnishes a check on the plant inspector.

The usual daily plant analysis consists of a mechanical sieve analysis of the hot aggregate as it runs into the batch box. If it varies much from the desired amount, the method of feeding the various sizes to the drum should be changed. The proportioning of the different sands and stones to the drying drum is often very crudely done and results in a non-uniform aggregate. This does not generally occur in large stationary plants but is a frequent source of trouble in small semi-portable road plants.

Checking Temperatures.—Probably the most important duty of the plant inspector on road jobs is to prevent overheating of the bitumen or stone aggregates as most of our failures are directly traceable to overheating. In small semi-portable plants, the storage bin for the aggregate is generally small and it is difficult to regulate the heat of aggregate running directly from drum to batch with small storage. *The plant inspector must under no circumstances permit overheating which is generally set at* 350 *deg. F.*

Time of Mix.—Minimum time of mix recommended by Asphalt Assoc.

Binder Course	30 seconds.
Modified Topeka or Sheet Asphalt Surface	60 seconds.

Record of Output.—A record of the weight and temperature of each load is made, see page 327.

Field Inspection.—The inspection of grading, culverts and macadam bases are the same as discussed under Macadam, pages 217 and 229.

The essentials of inspection of concrete paving base is the same as for concrete pavement (see pages 277 to 291) in regard to subgrade, form setting, mixing and placing except that the finishing requires different procedure and while the curing must not be neglected and requires earth cover and sprinkling, it does not require burlap or canvas covers immediately following the placing.

The surface of the concrete base must not show porosity or voids of any kind and the coarse aggregate must be embedded but a smooth glassy surface is undesirable as the binder coat does not get a good grip and tends to shove more readily into waves. The same care must be exercised to get a uniform crown and longitudinal profile as depressions or humps in the foundation eventually produce an uneven surface due to the impossibility of laying unequal depth surface mix with the same degree of compaction. *The surface mix must be uniform in thickness.*

City of Rochester, N. Y. Specifications limit the variation in depth of surface mix as follows: "The surface thickness shall not be less than 2 in. Not more than 10 per cent excess thickness will be permitted at any one spot."

Inspection of Laying Asphaltic Surface.—The inspection of laying and compacting the binder and surface layers of asphaltic concrete includes: Approval of the condition of the concrete or macadam, base, checking the depth of spread, temperature of mix as delivered, amount of rolling and true shape of finished surface.

Condition of Base.—The base must have set a sufficient time and be well hardened. Specifications for the time of curing of cement concrete bases range from 7 to 21 days. Fourteen days is a reasonable length of time in warm weather which should be increased to 21 days in the fall when the temperature falls below 50 on the average.

The base must be clean and free from dust, mud or organic deposits or leaves. It should be broomed just prior to laying the asphaltic mix.

The base must not be wet. Slight dampness does no harm but no asphaltic mix should be laid during rain or when the base has any pools of water or any snow on its surface.

Binder Course.—Binder should be laid only as far ahead of the surface as needed for keeping the work moving and should never be more than a day in advance of the surface mix. If such binder develops flaws such as poor bond or becomes broken up under traffic, it must be removed and replaced with fresh material.

Temperature of Mix.—The plant inspector is supposed to prevent overheating so that the usual point for the field inspector to watch is minimum temperature. This is generally set at 200 deg. F. Once in a while a hot load gets by the plant inspector, which can be easily detected at the road as the load will develop a heavy white smoke when dumped. Maximum temperature is usually set at 325 deg. F. at the street or 350 deg. F. at the plant.

Thickness of Spread.—Thickness of spread is regulated by weight. Each driver is furnished by the plant inspector with a card certifying weight of load. This card is given to the field inspector who regulates the distance (number of square yards) that each load should cover. For all practical purposes, the ordinary surface mix (Topeka) weighs about 105 lb. per square yard per inch thickness of consolidated finished depth. The weight of binder depends on the mix used; it is usually paid for by the ton and put on under a specification of a certain number of pound per square yard. The record of weight and surface area is illustrated on page 327.

The mix must be dumped ahead of the spread and entirely rehandled by spreading with hot shovels and raked to final shape with hot rakes.

Joints.—All joints where work is stopped at noon or night must be cut back square vertical edges to full depth and painted with hot asphalt.

Rolling and Finish.—As soon as practicable, the surface should be rolled with a light (3-ton) tandem roller and the final compression obtained with a 7- or 8-ton tandem. Rolling is important. It requires not only the ordinary straight roll but also cross-rolling to produce a smooth result. The minimum amount of rolling is usually set at about 200[1] sq. yd. per hour for roller. The finished surface should show no depressions or humps of over $\frac{3}{8}$ in. as measured by a 10-ft. straight-edge placed longitudinally to the road.

The use of two rollers of different weights is desirable particularly in cool weather or on macadam bases. The light roller can get on the hot mix quicker which prevents cracking liable to develop in cool weather due to the surface cooling much more rapidly than the body of the mix.

The following quotation gives rolling specifications in detail:

Compacting Surface Course.—While still hot the surface course shall be thoroughly and uniformly compressed by a power driven tandem roller weighing not less than seven (7) tons, except that initial compression may be obtained by a power driven tandem roller weighing not less than three (3) tons. Rolling shall start longitudinally at the sides and proceed toward the center of the pavement, overlapping on successive trips by at least one-half the width of the roller. The pavement shall then be subjected to diagonal rolling in two directions the second

SEPT. 29, 1914. PLANT RECORD

Load record				Bitumen record	
Load	Time	Temperature of mix, degrees Fahrenheit	Weight of load, pounds	Time	Temperature, degrees Fahrenheit
1	7.30	320	5,000	7.00	310
2	7.45	310	5,000	8.00	345
3	7.55	300	6,000	9.00	340
4	8.15	300	6,000	10.00	310
5	8.25	290	5,000	11.00	305
6 etc.	8.45	310	5,000	12.00	320

TEST SAMPLE 7. SEPT. 29, 1915. ROAD RECORD

Load No.	Time	Temperature of mix, degrees Fahrenheit	Weight as per ticket, pounds	Number yards covered	Location on road
1	8.00	310	5,000	25	Sta. 10+30 to 10+42
2	8.20	300	5,000	25	Sta. 10+42 to 10+54
3	8.30	295	6,000	30	Sta. 10+54 to 10+69
4	8.45	295	6,000	30	Sta. 10+69 to 10+84
5 etc.	9.00	280	5,000	25	Sta. 10+84 to 10+96

[1] See also p. 335 (100 sq. yd. per hour).

diagonal rolling crossing the lines of the first. If the width of the pavement permits, it shall in addition be rolled at right angles to the center line. Rolling shall be continued until all roller marks are eliminated. The motion of the roller shall at all times be slow enough to avoid displacement of the hot mixture and any displacements occurring as a result of reversing the direction of the roller, or by any other cause shall at once be corrected by the use of rakes and of fresh mixture where required. Rolling shall proceed at an average rate of not to exceed two hundred (200) square yards per hour per roller, and shall continue until no further compression is possible. To prevent adhesion of the surface mixture to the roller, the wheels shall be kept properly moistened, but excess of either water or oil will not be permitted. Before final compression a light uniform coating of limestone dust or Portland cement shall be swept over the surface of the pavement and the rolling then continued.

General Maintenance Methods.—Usual methods of shoulder, ditch and guard rail work prevail. The pavement is repaired by cutting out the depressions or waves which develop and replacing the surface mix; this can be easily and quickly done with very little inconvenience to traffic (see Chap. IV for costs, etc.).

Typical Specifications.—The following typical specifications New Jersey (1922) give an idea of Standard Practice for different types of bituminous concrete pavements.

TYPICAL SPECIFICATIONS

NOTE.—Where materials are referred to in these Specifications the clauses mentioned appear in Appendix A, pages 546 to 580.

FOUNDATION TYPE C

74A. PORTLAND CEMENT CONCRETE

1. COMPOSITION.

This foundation shall be prepared from concrete having the following composition: Portland cement one (1) bag, fine aggregate three (3) cubic feet, coarse aggregate five (5) cubic feet by volume, unless the character of the aggregate is such that the specified quantity of cement required per cubic yard is not secured. In such cases, the ratio of cement to fine aggregate or of fine aggregate to coarse aggregate, shall be changed as herein provided so that the specified quantity of cement will be secured per cubic yard of concrete. The Contractor will receive no additional compensation for making such changes.

Concrete headers, when integral with the foundation, shall be constructed of the same aggregate used in the foundation, but shall have the following composition: Portland cement, one (1) bag; fine aggregate, two (2) cubic feet; coarse aggregate, four (4) cubic feet.

2. MATERIALS REQUIRED.

Cement—The cement shall meet the requirements given in Article 96.

Fine Aggregate—The fine aggregate shall be concrete sand as defined in Article 95b.

Coarse Aggregate—The coarse aggregate shall be trap rock, dolomite, or....., concrete size or grade as specified in Articles 92 to 94 inclusive.

Cement and Aggregate—Before any orders are placed or deliveries made, the Contractor shall obtain the Engineer's written approval of the cement, fine and coarse aggregates he intends to use. In making requests for said approval, the Contractor will give the name, producer, location, and method of shipment of these materials.

Water—All water used in concrete shall be clean, free from oil, acids, alkalies, sea salts, vegetable matter, or ingredients that are injurious to concrete.

Joint Filler—All joint fillers used shall comply with the requirements given therefor in Article 103 for Grade M. A. Joint Fillers.

3. General.

The completed foundation shall have the width, thickness and surface contour shown on plans.

A cubic yard of concrete shall contain not less than four and sixty-four hundredths (4.64) bags of cement.

The Engineer shall compare the calculated amount of cement required according to these specifications, with the amount actually used, as determined by actual count of the number of bags of cement used per day. If the amount of cement used during any three (3) consecutive days is less by more than five (5) per cent., or if the amount of cement used during any one day is less by more than ten (10) per cent of the amount hereinbefore required, the Contractor shall, at his own expense, remove all such concrete and replace the same with new concrete, constructed according to these specifications.

The subgrade must comply with the requirements specified in Articles 67, 68 and 73. In addition it must be kept constantly wet at least fifty (50) feet in front of the mixer. To secure the desired depth of saturation, the subgrade shall be sprinkled at frequent intervals. The rapidity with which the water shall be applied and the quantity used shall vary with the character of the subgrade. The depth of saturation for sand and gravel subgrades shall not be less than four (4) inches, for clay and clay loam subgrades not less than three (3) inches. The rate the water is applied and method of sprinkling employed, shall be such as not to form pools of water on the surface of the subgrade yet all parts of the subgrade must be saturated to the depth required before any concrete is applied thereon.

After the subgrade has been properly wet it must be protected in the manner ordered by the Engineer so that ruts are not formed during the hauling of the aggregate or paving mixtures.

All materials used in a concrete foundation must be kept clean during transportation and hauling. Neither the coarse or fine aggregate shall be deposited upon the subgrade shoulders or adjacent gutters unless permission is given therefor in the "Proposal." When deposited in piles adjacent to the work the ground upon which the material is deposited must be hard, firm, well drained and free from all vegetable matter. All devices used in measuring these aggregates shall be so constructed that they will hold the exact volume of material required, and meet the approval of the Engineer.

No concrete shall be prepared or laid until the condition of the equipment that will be used in the preparation thereof has been approved in writing by the Engineer. This approval will be required for each contract and shall be requested by the Contractor sufficiently in advance of starting work to permit of any required changes being made without delaying the work.

The Contractor shall provide such measuring devices as will insure the required quantity of each ingredient being used in each batch. All such devices and the method of measuring the materials must be approved by the Engineer. A bag of portland cement ninety-four (94) pounds net, shall be considered as one (1) cubic foot.

The proportions of fine and coarse aggregate required to be used to secure the specified cement content, also the consistency required and the crushing strength of the concrete thus prepared, shall be determined by the Engineer. These factors must be determined for each contract during the preparation of the initial concrete. No concrete shall be laid until they have been thus determined. When so determined they shall only be changed when the required cement content is not being secured. The Construction Inspector shall notify the Engineer when the initial concrete will be prepared, said notice to be given at least five (5) days previous to its preparation, also whenever the required cement content is not being secured.

Concrete shall not be mixed or laid when the atmospheric temperature in the shade or the temperature of the aggregate is at or below 32 deg. F. When written permission is secured from the Engineer to construct pavement when the temperature drops below 32 deg. F. at night, the concrete must be protected from freezing by one of the following methods. Any concrete that has been frozen before it is five days old shall be replaced.

1. After the strips of canvas or burlap have been removed, the concrete shall be covered with a six (6) to eight (8) inch layer of straw or salt hay over which a canvas cover shall be spread and firmly fastened in place. This cover shall be at least four (4) feet longer than

the pavement is wide, laid across the pavement with edges overlapping, and the edges of each layer firmly fastened in place by straps or weights. Upon this canvas there is then placed another layer of straw if the weather is fairly severe.

2. Boards are placed across the center of the concrete at frequent intervals upon which a steam pipe is laid. The entire pavement is then covered with wooden trestles slightly longer than the pavement is wide and which are of sufficient height to leave an air space of not less than six (6) inches above the pavement surface. These boards are then covered with canvas or strips of tarred paper which must be firmly fastened in place. Steam is then passed through the pipe until the weather has moderated or the pavement is at least five days old.

During very severe weather this method of protection should always be used and it may be found necessary in extreme cases to cover the canvas with a layer of salt hay or straw.

4. Surface Finish.

The finished surface of the concrete shall be uniform in appearance, free from all loose or partly imbedded stone, lean or porous spots, depressions or projections that are over three-eighths (3/8) inch above or below the specified surface of the concrete as determined by a straight edge, not less than ten (10) feet long laid parallel to the center line of the pavement. It must also be at the required grade and parallel to the finished surface at all points.

5. Consistency.

The consistency of the concrete shall be determined by the slump method. When the slump has been determined for concrete containing a given aggregate, no subsequent concrete prepared from these aggregates shall have any greater slump. All concrete that has a greater slump shall be removed from the roadway before any initial set has developed. Said slump shall be determined with a truncated cone twelve (12) inches high, eight (8) inches diameter at the base, and four (4) inches diameter at the top.

When the required consistency of the concrete has been established by the method defined above, the crushing strength of this concrete shall be determined by six (6) inch cubes. These cubes, and all subsequent cubes taken and tested, shall be moulded and cured in the field in the same manner, and tested when twenty-eight (28) days old. In determining the average crushing strength of this concrete, not less than three (3) nor more than five (5) cubes shall be taken at irregular intervals from different batches of concrete. When the average strength of this concrete has been thus determined, all subsequent concrete prepared from the same aggregates shall have a crushing strength of not less than seventy-five (75) per cent of this average, and not more than ten (10) per cent of the individual samples shall have a crushing strength less than ninety (90) per cent of this average.

6. Mixing Concrete.

The materials shall be mixed in a concrete mixer of the batch type, having a capacity of not less than three (3) bags of cement per batch of concrete of the composition herein specified. Said mixer shall be equipped with an automatic locking device that will prevent materials being discharged before thay have been in the mixer the required length of time, a water tank containing an adjustable overflow with the necessary valves to prevent water flowing into the tank while the tank is discharging into the mixer, and a speed regulator that will prevent the drum from revolving slower than twelve (12) or faster than twenty (20) revolutions per minute. Each batch must be in motion in the mixing drum at least one and one-quarter (1¼) minutes or as much longer as may be necessary to insure a uniform and homogeneous concrete that has the required consistency. If the timing device should be out of order, the concrete must be mixed not less than two and one-half (2½) minutes until such time as said device is repaired. The drum must be completely emptied before mixing successive batches. The concrete shall be mixed only in such quantity as will be required for immediate use. Any concrete that has developed initial set or has been mixed longer than thirty (30) minutes before being deposited in place, shall not be used.

The different ingredients used must be perfectly clean, kept free from foreign materials during the operation of handling, mixing, and placing. The Contractor must prevent any segregation of the coarse or fine particles of the aggregate taking place during hauling or the handling, or the inclusion therewith of any foreign material when these materials are loaded into the measuring bins or mixer.

The Contractor shall notify the Engineer, in writing, at least three (3) days in advance when he is ready to prepare the initial concrete.

7. Placing Concrete.

After mixing, the concrete shall be deposited at once in successive batches upon the subgrade to the required depth and for the entire width of the pavement. Immediately after being thus deposited, the piles or batches of concrete shall be uniformly distributed over the subgrade so that the resulting surface is fairly uniform in character, and sufficiently above the grade of the finished surface that, after being struck off the surface thereof will not be compressed below the grade specified therefor.

When concrete is to be placed adjacent to railroad tracks, or around such structures as catch basins, manhole tops, or other objects that project through the pavement, no concrete shall be placed within eighteen (18) inches of said tracks or structures until they have been set to the required grade and alignment.

8. Finishing Concrete.

The concrete shall be brought to the required grade and curvature by the use of a hand strike board. This board must be at least eighteen (18) inches longer than the pavement is wide. A hand template shall be used to consolidate the concrete and produce the required finish. Both the strike board and template shall have the same curvature as that specified for the crown of the pavement.

After being properly placed the concrete shall be struck off and the whole surface thereof tamped until thoroughly consolidated and of a uniform consistency and density. Additional concrete shall be added to all low places and porous spots, and retamped to the required grade and density. The concrete should not be tamped to the required grade and solidity later than thirty (30) minutes after placing, but must be properly struck off and tamped before any initial set has developed.

9. Curing and Protecting.

After the concrete has been properly struck off, tamped and tested, it shall be covered at once with strips of burlap or canvas laid perpendicular to the center line of the pavement. The edge of each strip shall overlap the adjacent strips about one (1) inch. The different strips of burlap shall be at least two (2) feet longer than the width of the pavement.

When properly placed this covering shall be sprinkled at once with sufficient water to saturate it and kept wet until removed. As soon as the concrete has hardened sufficiently to prevent pitting, these strips shall be removed and the concrete protected by covering it immediately with salt hay or straw. This covering shall be spread in a layer not less than six (6) inches thick, loose, and must be added in sufficient quantity to completely cover the concrete. During the spreading, care must be exercised that the surface of the concrete is not marred or injured. As soon as spread, it shall be wet at once and kept constantly saturated for at least ten (10) days. The pavement must be kept closed to traveling public, contractor, engineers and officials, for at least fourteen (14) days, and as much longer as the Engineer may order.

The water pipe, which supplies the water for the concrete must not be removed before the time required for the curing of the adjacent concrete. This pipe line must be provided with tees and stop cocks at intervals of not over two hundred (200) feet and must be of sufficient size to permit of the proper sprinkling of the concrete and the operation of the concrete mixer at the same time.

The Contractor shall erect and maintain suitable barricades to protect the concrete from traffic, domestic animals, etc. Any part of the concrete damaged from traffic or any other cause occurring prior to its final acceptance, shall be repaired or replaced by the Contractor at his own expense in a manner satisfactory to the Engineer. Before any surface pavement materials are deposited on the foundation, the covering shall be removed and disposed of as directed by the Engineer.

If permission is given to lay concrete when the temperature may drop below thirty-two (32) degrees Fahrenheit before the concrete is five (5) days old, the concrete shall be protected in the manner specified above.

10. Side Forms.

The thickness of the pavement foundation and its alignment shall be determined by side forms. These shall be set to the established line and grade of the pavement foundation with their upper faces at the grade established for the adjacent edge. They must be equal in width to the thickness of the pavement foundation at the edge, shall be firmly held in place by lock nuts, clamps, and steel pins, and supported at all joints or elsewhere as needed

to prevent the forms from springing out of alignment. All forms shall have square ends with clamping devices which will lock adjacent ends firmly together. The anchoring pins must be not less than twenty-four (24) inches long, and of sufficient size to firmly hold the forms in place. No pins, nuts or clamps shall project above the top of the form or be so placed as to interfere with the free movement of the strike board or tamper. All forms must be straight, free from warp, clean when used, and oiled if so ordered. Forms shall not be removed sooner than fifteen (15) hours after the adjacent concrete has been placed.

11. Joints.

Expansion joints shall be constructed at the end of each day's work, or when work is suspended for over thirty (30) minutes, and at all other places designated on plans.

Expansion joints shall be of either the poured or premoulded type. When the type to be used is not designated on plans, the Contractor may construct either. The bitumen used to form the joints and the method of manufacturing premoulded joints must comply with the requirements given therefor in Article 103.

The forms used to cast a poured joint must be so designed and used that the concrete will not be injured by its removal, the opening will have the specified dimensions, be perpendicular to the pavement surface and axis must be approved by the Engineer. They shall be so set that the top edge is at the same elevation as the surface of the concrete and firmly held in place by iron rods or pins driven into the subgrade.

The bitumen used for pour joints shall be Grade P. A. and shall be applied at a temperature between 300 and 400 deg. F. Sufficient bitumen shall be used to fill the joint flush full. The joint must be opened to full depth and both faces clean and dry when the bitumen is applied.

Premoulded joints shall be formed by inserting during construction, sheets of bituminized felt or prepared semi-solid bitumen complying with the requirements given therefor in Article 103. These sheets shall be inserted perpendicular to the axis of the pavement and its surface. They shall be equal in length to the width of the foundation, have the same width as the thickness specified for said foundation, and the top edges cut to the required curvature before installation. When two sheets are used for one joint, the abutting ends must be cut square and held firmly together during installation, placing and finishing of the concrete. After side-forms are removed, the ends of the joints shall be cleaned of all concrete to the full depth.

The device used to hold the joint filler in position until the adjacent concrete has been placed, shall be a metal plate equal in length to the width of the foundation, have one edge cut to the crown specified for the surface of the foundation, be of sufficient thickness, and so designed that it can easily be fastened and held in place without springing out of shape or alignment.

12. Reinforcement.

The concrete shall be reinforced at all points shown on plans with the size and type of metal designated, also at all places where trenches or other openings are made in the subgrade for the installation of drains or structures not shown on plans. When no method of reinforcing the concrete over openings made in the subgrade is shown on plans, it shall be reinforced as follows:

One-half (½) inch deformed bars shall be placed perpendicular to the trench, two (2) inches above the bottom of the concrete foundation, spaced twelve (12) inches to centers and shall extend for a distance at least twelve (12) inches beyond each edge of the opening. Payment will be made for all such reinforcement installed, not shown on plans, at the contract unit price per pound in place.

Surface Type S. A.

75C. SHEET ASPHALT

Two Course

1. Definition.

A sheet asphalt pavement is one in which the wearing surface is composed of bituminous sand and mineral filler, bound together with an asphaltic cement. It is usually laid in two courses—the top or wearing surface and the bottom or binder course.

2. Thickness and Weight.

The top course must have an average thickness after ultimate compression of not less than one and one-half inches (1½ in.), shall not be less than one and one-quarter inches (1¼ in.) nor more than two inches (2 in.) thick at any one point, and shall have an average weight of not less than one hundred fifty (150) pounds per square yard.

The bottom course shall have an average thickness after ultimate compression of not less than one and one-half inches (1½ in.), shall not be less than one and one-quarter inches (1¼ in.) nor more than two and one-half inches (2½ in.) thick at any one point, and shall have an average weight of not less than one hundred seventy (170) pounds per square yard.

3. Materials Required.

The top or wearing surface shall be prepared from bituminous sand, mineral filler and asphaltic cement, Grade LM[1], CM[1], NA[1] or.....

The bottom or binder course shall be prepared from ¾-in. trap rock, dolomite or..... bituminous sand and asphaltic cement, Grades LM[1], CM[1], NA[1] or .....

These materials shall comply with the requirements given in Articles 92, 95*A*, 97 and 99

4. Composition.

The finished pavement must not vary in composition more than the limits given below:

Screens and sieves		Type of opening	Bottom course		Top course	
Passing	Retained on		Minimum, per cent	Maximum, per cent	Minimum, per cent	Maximum, per cent
1½-in.	1-in.	circular	0.0	25.0		
1-in.	½-in.	circular	40.0	70.0		
½-in.	¼-in.	circular	5.0	20.0		
¼-in.	10-mesh	square	00.0	15.0	....	2.0
10-mesh	30-mesh	square	3.0	10.0	10.0	30.0
30-mesh	50-mesh	square	4.0	8.0	15.0	30.0
50-mesh	80-mesh	square	4.0	8.0	15.0	30.0
80-mesh	200-mesh	square	3.0	12.0	12.0	28.0
200-mesh filler	.....	square	0.0	5.0	12.0	20.0
Total stone content—retained on 10-mesh.....			75.0	90.0	0.0	2.0
Bitumen content.....			4.0	5.5	10.5	12.5

5. Estimating Ingredients.

The proportions of the different ingredients required to prepare the pavement shall be determined by weight. The pavement must not vary in composition more than the specified limits given.

The bitumen content is based upon the finished pavement, exclusive of any mineral or bituminous surface coating applied. The exact amount of mineral filler and asphaltic cement to use between the limits defined herein shall be determined by the Testing Engineer. In calculating the percentages of the various sizes of ingredients of which the mineral aggregate is composed, the bitumen is included. The actual amount of paving mixture used shall be estimated from the railroad shipping weights of the ingredients used, batches of paving mixtures prepared and used, or loads delivered and laid.

6. Preparation.

The quantity of ingredients used per batch in the preparation of both the top and bottom courses must be accurately determined by either weight or measurement, depending upon the type of plant and kind of material being used. In either case the devices used in measuring these ingredients must be standardized whenever so requested; also the manner in which these devices are used shall be demonstrated and the quantity of material thus

secured verified whenever so ordered by the Inspector or Engineer. The plant used in preparing the paving mixtures shall comply with the requirements given below.

The mineral filler should be so cast into the mixing chamber that it is evenly distributed over the surface of the sand and not dumped in one end of the mixing chamber. The asphaltic cement should also be added slowly in a thin sheet the full width of the mixing chamber. If the filler and asphaltic cement are not added in this manner, the time required to produce a uniform paving mixture will be two or more minutes per batch, otherwise from 1 to 1½ min. will be sufficient.

(*a*) Wearing Surface. The sand for the wearing surface must have a temperature of not less than 300 deg. F. nor more than 400 deg. F. when ready to be coated with the asphaltic cement. The asphaltic cement, when applied to the aggregate, must have a temperature of not less than 250 deg. F. nor more than 350 deg. F., and must be free from unmelted lumps. The mineral filler may be added cold, but must be thoroughly dry.

In the preparation of this mixture the sand is first added to the mixing chamber, then the mineral filler. After the mineral filler has become uniformly distributed through the sand the asphaltic cement is added and the mixing continued until a bituminous mixture is secured that is uniform and homogeneous in composition and all the particles of the aggregate are uniformly and completely coated with the hot asphaltic cement.

(*b*) Binder Course. The aggregate for the binder course must have a temperature of not less than 250 deg. F. nor more than 350 deg. F. when ready to be coated with the asphaltic cement. The asphaltic cement shall have the same temperature when applied as specified for the wearing surface. No mineral filler is required in the binder.

In preparing the binder course, the stone and sand are run into the mixing chamber and the asphaltic cement added as soon as the sand is thoroughly incorporated with the stone. The mixing is continued until all particles of the aggregate are completely coated with hot asphaltic cement and the mixture is uniform and homogeneous in composition. Care must be exercised in the preparation of this binder that the aggregate does not get too hot; that excess fine materials or asphaltic cement are not used if rich spots in the binder are to be avoided.

7. Hauling and Handling.

The paving mixtures must be kept clean during hauling and handling, and covered during transit with canvas or other materials which will retain their temperature. These mixtures must not be hauled such a distance that segregation of the ingredients takes place, or that a crust is formed on the surface, bottom or sides of said mixture which has a temperature lower than that required. These mixtures must not be dumped any faster than they can be properly handled by the shovelers, nor at such a rate that over 6 tons of paving mixture are upon the platforms at the same time. They must be spread immediately after being dumped and must be kept perfectly clean until spread. Any part of the paving mixture which becomes dirty or chilled below the required temperature must be rejected. All paving mixture must be carefully removed from the spot upon which it was placed before any additional paving mixture is placed thereon.

The mixture for the wearing surface, when dumped on the platforms, must have a temperature between 275 deg. F. and 350 deg. F.; for the binder course, between 250 deg. F. and 325 deg. F. Any portions of the wearing surface mixture that become chilled below 250 deg. F. or of the binder below 225 deg. F. before being spread shall be discarded.

These paving mixtures may be dumped direct on a concrete foundation, but when the foundation is macadam or telford they shall be dumped on metal or wooden platforms, which must be of such size that the paving mixture will not fall off when dumped thereon or work off during spreading. The wearing surface mixture may be dumped on the binder. However, each load of paving mixture must be dumped outside of the area over which it will be spread.

All vehicles used in transporting paving mixtures must have tight-fitting bottoms which will hold hot, thin mixtures without leaking. When motor trucks are used the bodies should be insulated for long hauls during cold weather so that the paving mixtures adjacent the ends and sides will not become chilled during transit. All motor trucks used for this purpose must have dump bodies that will permit the rapid unloading of these mixtures. The inside surface of these bodies should be oiled just before loading. However, only sufficient of this oil shall be used to coat the surface. No pools of oil must appear on the bottom of the truck.

8. Spreading and Raking.

Immediately after a paving mixture has been dumped upon the platform it shall be deposited at once upon the foundation or binder with hot shovels in such a manner that any segregation of the ingredients or irregularities in composition will be eliminated as much as possible. After being thus deposited it shall be so spread with hot iron rakes that after being thoroughly compacted by tamping and rolling each course shall have the average thickness, surface finish and contour specified below.

During spreading and raking the workmen must not walk over or stand on the paving mixture except when necessary to correct irregularities in the initial raking. The paving mixture shall not be spread any faster than it can be properly handled by the rakers.

(*a*) Binder. The binder course shall only be rolled sufficient properly to compact and bind together the ingredients of the aggregate; also to disclose any open spots or low places. When any depressions are discovered they shall be filled with additional binder and rerolled so that the surface of this binder course shall be of a uniform character, at the required grade and have the specified crown.

The surface of the binder course after compression shall not show in any place an excess of asphaltic cement or fine matrix, and any area of 1 sq. ft. or more showing an excess of asphaltic cement shall be cut out and replaced with proper binder. Smaller spots may be dried by the use of stone dust and smoothing irons.

After being spread and rolled as above specified the binder course must be protected from all travel and be kept perfectly clean until the top course has been applied. If any part of the binder course shows a lack of bond, becomes loose or broken, or gets covered with dirt, it must be replaced with proper material, laid in accordance with the requirements given.

The binder course, after being properly constructed, should be covered immediately with the top course. In no case shall more binder be laid during any one day that can be covered by the top course during the same day. No binder course should be left uncovered during the night. If it becomes coated with dust or dirt when left so uncovered it must be swept clean or replaced with proper material, as the Engineer may direct, before any surface course is applied thereto.

(*b*) Surface. Special care must be used in spreading and raking the wearing surface if porous spots, depressions or projections are to be eliminated. For this purpose the Contractor shall employ not less than three (3) rakers for each one hundred (100) square yards of surface pavement laid per hour. Additional rakers must be employed when a greater quantity of pavement is being laid per hour.

The rolling of the wearing surface mixture must be so executed that porous spots will be eliminated, the formation of waves and depressions prevented and the required density and surface finish secured.

Whenever the pavement is laid alongside of brick, concrete gutters, street car tracks, man-hole heads or liners, the finished surface adjacent to them shall be left one-quarter of an inch (¼ in.) high in order to provide for subsequent compression by traffic and to avoid depressions which would otherwise be liable to occur at these points.

9. Rolling.

After the paving mixtures have been properly spread and raked they shall be rolled as soon as they will bear the roller without undue displacement or hair cracking. Delays in the initial rolling of the freshly raked mixtures will not be permitted. In all places inaccessible to a roller, such as adjacent to curbs, gutters, headers, man-holes, etc., the required compression shall be secured with hot tampers.

The initial and final rolling of the binder course shall be done with a six (6) to eight (8) ton tandem roller or a ten (10) to twelve (12) ton three-wheel power roller. The initial rolling of the top course or wearing surface shall be done with a five (5) ton tandem roller, but final compression shall always be secured with an eight (8) to ten (10) ton tandem roller or a ten (10) to twelve (12) ton three-wheel power roller when the Engineer permits or requires the use of this type of roller.

When more than one hundred (100) square yards of wearing surface are laid per hour, two (2) rollers shall be kept in use, one of which shall be of the finishing size. An additional finishing roller will be required for each additional one hundred(100) square yards of wearing surface laid per hour. All rollers used shall be kept in good condition, and shall weigh not less than two hundred (200) pounds to the inch width of tread. Each roller shall be in the charge of a competent experienced roller Engineer, and must be kept in continuous

operation as nearly as practicable. During an 8-hour day each roller must be engaged in actual rolling for not less than six and one-half (6½) hours, not more than one and one-half (1½) hours being allowed for cleaning fires, watering, etc. The ashes from the roller must not be dumped upon the binder or wearing surface courses.

The surface of the wheels of the roller must be kept clean at all times and either oiled or wet with water as ordered by the Engineer. When the use of water is permitted it shall not be applied in such quantity that surplus water will run off of the wheels of the roller onto the pavement.

During the initial rolling of both the top and bottom courses the roller shall travel parallel to the axis of the pavement, beginning at each edge and working towards the center. Each trip of the roller shall overlap the preceding one about one-half (½) the width of the roller. Alternate trips of the roller should be of slightly different lengths. Subsequent rolling shall be both diagonal and parallel to the axis of the pavement. The rolling shall be continued at the rate of not more than one hundred fifty (150) square yards of wearing surface per hour for each roller of the finishing size. The roller must not pass off the pavement during rolling, nor stand on the completed pavement which has not cooled to normal temperature.

The rolling should be so executed that all parts of the pavement will receive equal compression; also develop any low or high spots caused by improper spreading and raking. The surface of low spots or depressions shall be roughened with a hot rake, additional material added thereto and rerolled immediately. Excess material shall be removed from the high spots. Such repairs should be made as soon after the initial rolling as possible, while the pavement is yet fairly soft.

10. Surface Finish.

The surface of the finished pavements must substantially conform to the grade and contour specified and shall be free from depressions or projections which are one-quarter (¼) of an inch above or below the established grade as determined by a straight edge, five (5) feet in length, laid parallel to the axis of the road. It must be uniform in density and composition, thoroughly bonded together and water tight, and be free from porous or rough spots that will remain wet after the balance of the surface is dry. Such portions of the completed pavement as are defective in finish, or that do not comply in all respects with the requirements of these specifications shall be taken up, removed and replaced with suitable material, properly made and laid in accordance with the requirements of these specifications at the expense of the Contractor. Whenever so ordered by the Engineer a space of twelve (12) inches in width adjacent to the curb shall be coated with hot asphaltic cement which shall be ironed into the pavement with smoothing irons. The cement used for this purpose shall be the same as that used in preparing the paving mixture.

11. Joints.

The paving shall be so done that the number of joints required shall be reduced to a minimum. When a rope joint is not used the edges of the previously laid pavement shall be cut off in a straight line far enough back from the edge to insure that the wearing surface has the required thickness. The cut shall be made at a slight angle to the pavement surface and present a smooth unbroken edge. The face of the joint shall be painted with bituminous cement, after which the hot bituminous mixture shall be raked over it to the proper depth. Hot smoothers or tampers shall be carefully employed in such a manner as to insure the proper bond between the two (2) paving mixtures without burning or injuring either. The finished joint must be on the same plane as the adjacent finished pavement surface. Joints which are above or below the general plane of the pavement surface must be brought to the proper grade or remade.

The faces of all curbs and gutters, iron castings or other objects projecting through the pavement shall be painted with hot bituminous cement before the adjoining paving mixture is laid. The adjacent paving mixture shall be compressed by ramming with hot iron tampers when the required compression cannot be secured with the roller.

12. Foundation, Condition of.

The foundation, when a bituminous pavement is applied thereon, must be dry, clean, free from all frost and have a temperature above 32°F. at the point where the paving mixture is being laid. It must substantially conform to the grade and crown specified, and comply with the requirements given for the type of foundation being used. When a foundation is in the proper condition to receive a paving mixture it must be protected from all travel that will injure, deface or carry foreign material upon it.

13. Edge Protectors.

When the edges of pavements are not protected by a concrete or stone curb or header, four (4) to six (6) inch planks of the same thickness as the finished pavement must be used for this purpose, which shall be firmly secured and left in place until the pavement has been properly rolled and thoroughly set.

14. Construction Season.

The pavement shall be laid between the first day of May and the first day of December unless written permission is secured from the Department to lay pavement at any other time. No pavement shall be laid when it is raining or when the atmospheric temperature is below 32°F. or when the weather is such as to make it very difficult to lay the paving mixture in a manner which will permit the proper density and surface finish being secured.

15. Workmen.

The workmen employed by the Contractor must have had sufficient experience in the preparation of bituminous paving mixtures and the construction of bituminous pavements to be able to operate the equipment in such a manner that the pavement produced will have the required composition, density and surface finish. The men operating the mixing plant, the spreaders, rakers and roller men must show by the work completed that they have had the necessary experience and are making the proper effort to execute the work in the manner required by these specifications. Otherwise, their services will have to be dispensed with by the Contractor.

16. Plant and Equipment.

The plant used in preparing all bituminous paving mixtures must be of the batch type, capable of mixing in the manner herein specified, not less than ten (10) tons of paving mixture for each mixer per hour, and must be provided with separate chambers for heating and mixing the ingredients. No direct heat except steam shall be applied to the exterior surface of the mixing chamber or flame through the same. The aggregate shall be heated in a revolving kiln. The heat must be so regulated that the aggregate can easily be heated to and maintained at the required temperature. The temperature of the uncoated heated aggregate shall be determined by an electric pyrometer so placed at the discharge chute of the dryer as to automatically register the temperature thereof.

All mixing plants which do not dry and heat the aggregate in unit batches must be equipped with a twin-pug mixer, rotary screen, storage bins, hopper and scales.

The rotary screen must separate the aggregate into two or more sizes, exclusive of tailings. This screen must not be less than five (5) feet in length and contain the size openings necessary to produce a paving mixture of the composition herein specified.

The main bin into which the hot screened aggregate falls, must be divided to correspond to the different sized openings in the rotary screen and be so arranged that the aggregate from each size screen will pass into its respective bin without getting into the adjacent sub-bins. Each sub-bin must be provided with an overflow that will prevent excess material being accumulated in any one sub-bin. An overflow must also be provided to prevent all material larger than that permitted to be used in the pavement under construction from falling into any of the bins.

Each sub-bin must have a separate outlet with a gate at the bottom, and so arranged that any definite quantity of aggregate can be drawn therefrom. The hopper into which the hot aggregate is drawn must rest upon a set of scales so arranged that any definite weight of material can be weighed out of each sub-bin.

The mixer must be capable of holding and properly mixing at least a one thousand (1,000) pound batch of paving mixture. Each plant, regardless of the type of mixer used, must have at least two asphalt kettles holding not less than six hundred (600) gallons each, and an asphalt thermometer for use therewith. The heat must be applied to these kettles in such a manner that the asphalt cement will be uniformly heated without being burned or decomposed.

The asphalt carrier used to measure and apply the asphalt cement must be balanced upon a set of scales. It shall be so arranged that the asphalt cement can be easily and quickly weighed and poured in a thin sheet between the two lines of paddles the full width of the mixer.

When a squeegee distributor is required to be used, it must be designed for this particular purpose. All equipment and methods used in the preparation and construction of the pavement must be approved by the Engineer before being used on this contract.

17. Field Laboratory.

The Contractor shall provide and keep in good order at the plant the following testing equipment which may be used by the Engineer or Inspector.

1 Penetration Machine Complete with Dishes, Thermometer, Needles, Stop Watch, etc.

1 Laboratory Sand Scale, 500 grams capacity.

1 Set 6- to 8-in. Sieves, containing the following: Sizes 10, 20, 30, 40, 50, 80 and 200 meshes, with bottom pan and cover.

1 Set 6- to 8-in. Screens, 1¼, 1, ¾, ½ and ¼ in.

2 6-in. Pointed Trowels.

2 6- to 8-in. Steel Spatulas.

2 Brushes.

2 Or more Inspectors' Armor Asphalt Thermometers.

1 Roll Pat Test Paper.

The above equipment must be of standard type and approved by the Testing Engineer. The Contractor shall also provide a field laboratory in which to house and use the above equipment, said laboratory to be not less than ten (10) feet wide, twelve (12) feet long and seven (7) feet high, floored, contain not less than two windows and work bench with the necessary drawers; this laboratory to be used exclusively for testing purposes by the Contractor, Engineer or Inspector.

Surface Type FA-BC-1

751. FINE AGGREGATE. BITUMINOUS CONCRETE

One Course

1. Definition.

A bituminous concrete pavement is defined as one which is composed of clean stone-bituminous sand and a mineral filler, bound together with bituminous cement.

2. Thickness and Weight.

The pavement shall be laid in one course. It must have an average thickness of not less than two (2) inches after ultimate compression and shall not be less than one and three, quarters (1¾) inches nor more than two and one-half (2½) inches thick at any point, and shall have an average weight of not less than two hundred fifty (250) pounds per square yard of surface, exclusive of the squegee coat.

3. Materials Required.

This pavement shall be prepared from dustless screenings made from trap rock, dolomite or ....., bituminous sands, mineral filler and asphaltic cement, Grade NA^2, LM^2, CM^2, or.....

These materials shall comply with the requirements given therefor in Articles 92, 95-A and 99.

4. Composition.

The finished pavement, exclusive of any bituminous sealing mixture applied, shall not vary in composition more than the limits given below:

Screens and sieves		Type of openings	Minimum, per cent	Maximum, per cent
Passing	Retained on			
1-in.	½-in.	Circular	0.0	15.0
½-in.	¼-in.	Circular	20.0	45.0
¼-in.	10-mesh	Circular	10.0	25.0
10-mesh	30-mesh	Square	4.0	12.0
30-mesh	50-mesh	Square	6.0	12.0
50-mesh	80-mesh	Square	6.0	12.0
80-mesh	200-mesh	Square	5.0	11.0
200-mesh	.....	Square	5.0	8.0
Total stone content retained on 10-mesh sieve.....			50.0	70.0
Bitumen content.....			6.5	8.0

5. Estimating Ingredients.

The proportions of the different ingredients required to prepare the pavement shall be determined by weight. The pavement must not vary in composition more than the specified limits given.

The bitumen content is based upon the finished pavement, exclusive of any mineral or bituminous surface coating applied. The exact amount of mineral filler and asphaltic cement to use between the limits defined herein shall be determined by the Testing Engineer. In calculating the percentages of the various sizes of ingredients of which the mineral aggregate is composed, the bitumen is included. The actual amount of paving mixture used shall be estimated from the railroad shipping weights of the ingredients used, batches of paving mixture prepared and used, or loads delivered and laid.

6. Preparation.

The quantity of ingredients used per batch in the preparation of the paving mixture must be accurately determined by either weight or measurement, depending upon the type of plant and kind of material being used. In either case the devices used in measuring these ingredients must be standardized whenever so requested, also the manner in which these devices are used shall be demonstrated and the quantity of material thus secured verified, whenever so ordered by the Inspector or Engineer. The plant used in preparing the paving mixtures shall comply with the requirements given below.

The mineral filler should be so cast into the mixing chamber that it is evenly distributed over the surface of the aggregate and not dumped in one end of the mixing chamber. The asphaltic cement should also be added slowly in a thin sheet the full width of the mixing chamber. If the filler and asphaltic cement are not added in this manner, the time required to produce a uniform paving mixture will be two (2) or more minutes per batch, otherwise, from one (1) to one and one-half (1½) minutes will be sufficient.

The aggregate must have a temperature of not less than 275°F. nor more than 350°F. when ready to be coated with the asphaltic cement. The asphaltic cement when applied to the aggregate must have a temperature of not less than 250°F. and must be free from unmelted lumps. The mineral filler may be added cold, but must be thoroughly dry.

In the preparation of this mixture the stone and sand are first added to the mixing chamber, then the mineral filler. After the mineral filler has become uniformly distributed through the aggregate the asphaltic cement is added and the mixing continued until a bituminous mixture is secured that is uniform and homogeneous in composition and all the particles of the aggregate are uniformly and completely coated with the hot asphaltic cement.

7. Hauling and Handling.

The paving mixture must be kept clean during hauling and handling and covered during transit with canvas or other materials which will retain their temperature. The mixture must not be hauled such a distance that segregation of the ingredients takes place or that a crust is formed on the surface, bottom or sides of said mixture which has a temperature lower than that required. These mixtures must not be dumped any faster than they can be properly handled by the shovelers nor at such a rate that over six (6) tons of paving mixture are upon the platforms at the same time. They must be spread immediately after being dumped and must be kept perfectly clean until spread. Any part of the paving mixture which becomes dirty or chilled below the required temperature must be rejected. All paving mixture must be carefully removed from the spot upon which it was placed before any additional paving mixture is placed thereon.

The paving mixture when dumped on the platforms or foundation must have a temperature between 275°F. and 350°F. Any portions of the paving mixture that becomes chilled below 250°F. before being spread shall be discarded.

The paving mixture may be dumped direct on a concrete foundation, but when the foundation is macadam or telford, it shall be dumped on metal or wooden platforms which must be of such size that the paving mixture will not fall off when dumped thereon or work off during spreading. Each load of paving mixture must be dumped outside of the area over which it will be spread.

All vehicles used in transporting paving mixtures must have tight-fitting bottoms which will hold hot, thin mixtures without leaking. When motor trucks are used the bodies should be insulated for long hauls during cold weather so that the paving mixtures adjacent the ends and sides will not become chilled during transit. All motor trucks used for this

purpose must have dump bodies that will permit the rapid unloading of the mixture. The inside surface of these bodies should be oiled just before loading. However, only sufficient of this oil shall be used to coat the surface. No pools of oil must appear in the bottom of the truck.

8. Spreading and Raking.

Immediately after the paving mixture has been dumped upon the platform, it shall be deposited at once upon the foundation with hot shovels in such a manner that any segregation of the ingredients or irregularities in composition will be eliminated as much as possible. After being thus deposited it shall be so spread with hot iron rakes that after being thoroughly compacted by tamping and rolling it shall have the average thickness, surface finish and contour specified.

During spreading and raking the workmen must not walk over or stand on the paving mixture except when necessary to correct irregularities in the initial raking. The paving mixture shall not be spread any faster than it can be properly handled by the rakers.

Special care must be used in spreading and raking the wearing surface if porous spots, depressions or projections are to be eliminated. For this purpose the Contractor shall employ not less than three (3) rakers for each one hundred (100) square yards of surface pavement laid per hour. Additional rakers must be employed when a greater quantity of pavement is being laid per hour.

The rolling of the paving mixture must be so executed that porous spots will be eliminated, the formation of waves and depressions prevented and the required density and surface finish secured.

Whenever the pavement is laid along side of brick or concrete gutters, street car tracks, man-hole heads or liners, the finished surface adjacent to them shall be left one-quarter ($^1_4$) of an inch high in order to provide for subsequent compression by traffic and to avoid depressions which would otherwise be liable to occur at these points.

9. Rolling.

After the paving mixture has been properly spread and raked it shall be rolled as soon as it will bear the roller without undue displacement or hair cracking. Delays in the initial rolling of the freshly raked mixtures will not be permitted. In all places inaccessible to a roller, such as adjacent to curbs, gutters, headers, man-holes, etc., the required compression shall be secured with hot tampers.

The initial rolling of the paving mixture may be done with a five (5) to eight (8) ton tandem roller, but final compression shall always be secured with a ten (10) to twelve (12) ton three-wheel power roller.

When more than one hundred (100) square yards of wearing surface are being laid per hour, two (2) rollers shall be kept in use, one of which shall be of the finishing size. An additional finishing roller will be required for each additional one hundred (100) square yards of wearing surface laid per hour. All rollers used shall be kept in good condition and shall weigh not less than two hundred (200) pounds to the inch width of tread. Each roller shall be in the charge of a competent experienced roller engineer and must be kept in continuous operation as nearly as practicable. During an 8-hour day each roller must be engaged in actual rolling for not less than six and one-half ($6\frac{1}{2}$) hours, not more than one and one-half ($1\frac{1}{2}$) hours being allowed for cleaning fires, watering, etc. The ashes from the roller must not be dumped upon the foundation or wearing surface.

The surface of the wheels of the roller must be kept clean at all times and either oiled or wet with water as ordered by the Engineer. When the use of water is permitted, it shall not be applied in such quantity that surplus water will run off of the wheels of the roller onto the pavement.

During the initial rolling, the roller shall travel parallel to the axis of the pavement, beginning at each edge and working towards the center. Each trip of the roller shall overlap the preceding one about one-half ($\frac{1}{2}$) the width of the roller. Alternate trips of the roller should be of slightly different lengths. Subsequent rolling shall be both diagonal and parallel to the axis of the pavement. The rolling shall be continued at the rate of not more than one hundred fifty (150) square yards of wearing surface per hour for each roller of the finishing size. The roller must not pass off the pavement during rolling, nor stand on the completed pavement which has not cooled to normal temperature.

The rolling should be so executed that all parts of the pavement will receive equal compression; also develop any low or high spots caused by improper spreading and raking.

The surface of low spots or depressions shall be roughened with a hot rake, additional material added thereto and rerolled immediately. Excess material shall be removed from the high spots. Such repairs should be made as soon after the initial rolling as possible while the pavement is yet fairly soft.

10. Seal Coat.

As soon as possible after the rolling of the mixture is finished and while the surface is yet fresh, clean and hot, a seal coat of bituminous cement shall be spread thereon. The cement used for this purpose shall be the same as used in preparing the pavement mixture. It shall be applied at a temperature between 250°F. and 350°F. from a squegee distributor, and then evenly spread with rubber squeegees. Only sufficient cement shall be used to coat the surface and fill the surface voids without leaving an excess on the surface. Immediately over this a top dressing of dustless screenings or pea gravel, or a mixture thereof, shall be uniformly spread and rolled into the surface. Some surplus of this dressing shall be left on the surface.

11. Surface Finish.

The surface of the finished pavement must substantially conform to the grade and contour specified and shall be free from depressions or projections which are one-quarter (¼) of an inch above or below the established grade as determined by a straight edge, five (5) feet in length, laid parallel to the axis of the road. It must be uniform in density and composition, thoroughly bonded together and water tight, and be free from porous spots that will remain wet after the balance of the surface is dry. Such portions of the completed pavement as are defective in finish, or that do not comply in all respects with the requirements of these specifications, shall be taken up, removed and replaced with suitable material, properly made and laid in accordance with the requirements of these specifications at the expense of the Contractor.

12. Joints.

The paving shall be so done that the number of joints required shall be reduced to a minimum. When a rope joint is not used the edges of the previously laid pavement shall be cut off in a straight line far enough back from the edge to insure that the wearing surface has the required thickness. The cut shall be made at a slight angle to the pavement surface and present a smooth unbroken edge. The face of the joint shall be painted with bituminous cement, after which the hot bituminous mixture shall be raked over it to the proper depth. Hot smoothers or tampers shall be carefully employed in such a manner as to insure the proper bond between the two (2) paving mixtures without burning or injuring either. The finished joint must be on the same plane as the adjacent finished pavement surface. Joints which are above or below the general plane of the pavement surface must be brought to the proper grade or remade.

The faces of all curbs and gutters, iron castings or other objects projecting through the pavement shall be painted with hot bituminous cement before the adjoining paving mixture is laid. The adjacent paving mixture shall be compressed by ramming with hot iron tampers when the required compression cannot be secured with the roller.

13. Foundation, Condition of.

The foundation, when a bituminous pavement is applied thereon, must be dry, clean, free from all frost, and have a temperature above 32°F. at the point where the paving mixture is being laid. It must substantially conform to the grade and crown specified, and comply with the requirements given for the type of foundation being used. When a foundation is in the proper condition to receive a paving mixture it must be protected from all travel that will injure, deface or carry foreign material upon it.

14. Edge Protectors.

When the edges of pavements are not protected by a concrete or stone curb or header, four (4) to six (6) inch planks of the same thickness as the finished pavement must be used for this purpose, which shall be firmly secured and left in place until the pavement has been properly rolled and thoroughly set.

15. Construction Season.

The pavement shall be laid between the first day of May and the first day of December, unless written permission is secured from the Department to lay pavement at any other time. No pavement shall be laid when it is raining or when the atmospheric temperature is below 32°F., or when the weather is such as to make it very difficult to lay the paving mixture in a manner which will permit the proper density and surface finish being secured.

16. Workmen.

The workmen employed by the Contractor must have had sufficient experience in the preparation of bituminous paving mixtures and the construction of bituminous pavements to be able to operate the equipment in such a manner that the pavement produced will have the required composition, density and surface finish. The men operating the mixing plant, the spreaders, rakers and roller men must show by the work completed that they have had the necessary experience and are making the proper effort to execute the work in the manner required by these specifications. Otherwise, their services will have to be dispensed with by the Contractor.

17. Plant and Equipment.

The plant used in preparing all bituminous paving mixtures must be of the batch type, capable of mixing in the manner herein specified not less than ten (10) tons of the paving mixture for each mixer per hour, and must be provided with separate chambers for heating and mixing the ingredients. No direct heat except steam shall be applied to the exterior surface of the mixing chamber or flame through the same. The aggregate shall be heated in a revolving kiln. The heat must be so regulated that the aggregate can easily be heated to and maintained at the required temperature. The temperature of the uncoated heated aggregate shall be determined by an electric pyrometer, so placed at the discharge chute of the dryer as to register automatically the temperature thereof.

All mixing plants which do not dry and heat the aggregate in unit batches must be equipped with a twin-pug mixer, rotary screen, storage bins, hopper and scales.

The rotary screen must separate the aggregate into two or more sizes, exclusive of tailings. This screen must be not less than five (5) feet in length and contain the size openings necessary to produce a paving mixture of the composition herein specified.

The main bin into which the hot screened aggregate falls must be divided to correspond to the different sized openings in the rotary screen, and be so arranged that the aggregate from each size screen will pass into its respective bin without getting into the adjacent sub-bins. Each sub-bin must be provided with an overflow that will prevent excess material being accumulated in any one sub-bin. An overflow must also be provided to prevent all material larger than that permitted to be used in the pavement under construction from falling into any of the bins.

Each sub-bin must have a separate outlet with a gate at the bottom, and so arranged that any definite quantity of aggregate can be drawn therefrom. The hopper into which the hot aggregate is drawn must rest upon a set of scales so arranged that any definite weight of material can be weighed out of each sub-bin.

The mixer must be capable of holding and properly mixing at least a one thousand (1,000) pound batch of paving mixture. Each plant, regardless of the type of mixer used, must have at least two asphalt kettles holding not less than six hundred (600) gallons each, and an asphalt thermometer for use therewith. The heat must be applied to these kettles in such a manner that the asphalt cement will be uniformly heated without being burned or decomposed.

The asphalt carrier used to measure and apply the asphalt cement must be balanced upon a set of scales. It shall be so arranged that the asphalt cement can be easily and quickly weighed and poured in a thin sheet between the two lines of paddles the full width of the mixer.

When a squeegee distributor is required to be used, it must be designed for this particular purpose. All equipment and methods used in the preparation and construction of the pavement must be approved by the Engineer before being used on this contract.

18. Field Laboratory.

The Contractor shall provide and keep in good order at the plant the following testing equipment which may be used by the Engineer or Inspector.

1 Penetration Machine Complete with Dishes, Thermometer, Needles, Stop Watch, etc.

1 Laboratory Sand Scale, 500-gr. capacity.

1 Set 6- to 8-in. Sieves, containing the following: Sizes 10, 20, 30, 40, 50, 80 and 200 meshes, with bottom pan and cover.

1 Set 6- to 8-in. Screens, $1\frac{1}{4}$, 1, $\frac{3}{4}$, $\frac{1}{2}$ and $\frac{1}{4}$ in.

2 6-in. Pointed Trowels.

2 6- to 8-in. Steel Spatulas.

2 Brushes.

2 Or more Inspectors' Armor Asphalt Thermometers.

1 Roll Pat Test Paper.

The above equipment must be of standard type and approved by the Testing Engineer. The Contractor shall also provide a field laboratory in which to house and use the above equipment, said laboratory to be not less than ten (10) feet wide, twelve (12) feet long and seven (7) feet high, floored, contain not less than two windows and work bench with the necessary drawers; this laboratory to be used exclusively for testing purposes by the Contractor, Engineer or Inspector.

Surface Type FA-BC-2

75J. FINE AGGREGATE. BITUMINOUS CONCRETE

Two Course

1. Definition.

A bituminous concrete pavement is defined as one which is composed of clean stone, bituminous sand and a mineral filler, bound together with bituminous cement.

2. Thickness and Weight.

This pavement shall be laid in two courses—the top or wearing course and the bottom or binder course. The top course must have an average thickness, after ultimate compression, of not less than one and one-half (1½) inches, shall not be less than one and one-quarter (1¼) inches nor more than two (2) inches thick at any point, and have an average weight of not less than one hundred eighty-five (185) pounds per square yard, exclusive of the squeegee coat. The bottom course shall have an average thickness, after ultimate compression, of not less than one and one-half (1½) inches and shall not be less than one and one-quarter (1¼) inches nor more than two and one-half (2½) inches thick at any point, and have an average weight of not less than one hundred seventy (170) pounds per square yard of surface.

3. Materials Required.

The binder course shall be prepared from ¾-in. trap rock, dolomite or....., bituminous sand, mineral filler, and asphaltic cement Grades NA^2, LM^2, CM^2 or.....

The surface course shall be prepared from dustless screenings made from trap rock, dolomite or....., bituminous sand, mineral filler and asphaltic cement Grades NA^2, LM^2, CM^2, or.....

These materials shall comply with the requirements given therefor in Articles 92, 95-A and 99.

4. Composition.

The finished pavement, exclusive of any bituminous sealing mixture applied, shall not vary in composition more than the limits given below:

Screens and sieves		Type of openings	Bottom course		Top course	
Passing	Retained on		Minimum, per cent	Maximum, per cent	Minimum, per cent	Maximum, per cent
1½-in.	1-in.	Circular	0.0	25.0		
1-in.	½-in.	Circular	40.0	70.0	0.0	15.0
½-in.	¼-in.	Circular	5.0	20.0	20.0	45.0
¼-in.	10-mesh	Square	0.0	15.0	10.0	25.0
10-mesh	30-mesh	Square	3.0	10.0	6.0	18.0
30-mesh	50-mesh	Square	4.0	8.0	6.0	12.0
50-mesh	80-mesh	Square	4.0	8.0	6.0	12.0
80-mesh	200-mesh	Square	3.0	12.0	5.0	11.0
200-mesh	.....	Square	2.0	8.0	5.0	8.0
Total stone content ret. on 10-mesh.....			75.0	90.0	50.0	70.0
Bitumen content.....			4.0	5.5	6.0	8.0

5. Estimating Ingredients.

The proportions of the different ingredients required to prepare the pavement shall be determined by weight. The pavement must not vary in composition more than the specified limits given.

The bitumen content is based upon the finished pavement, exclusive of any mineral or bituminous surface coating applied. The exact amount of mineral filler and asphaltic cement to use between the limits defined herein shall be determined by the Testing Engineer. In calculating the percentages of the various sizes of ingredients of which the mineral aggregate is composed, the bitumen is included. The actual amount of paving mixture used shall be estimated from the railroad shipping weights of the ingredients used, batches of paving mixtures prepared and used, or loads delivered and laid.

6. Preparation.

The quantity of ingredients used per batch in the preparation of both the top and bottom courses must be accurately determined by either weight or measurement, depending upon the type of plant and kind of material being used. In either case the devices used in measuring these ingredients must be standardized whenever so requested, also the manner in which these devices are used shall be demonstrated and the quantity of material thus secured verified, whenever so ordered by the Inspector or Engineer. The plant used in preparing the paving mixtures shall comply with the requirements given below.

The mineral filler should be so cast into the mixing chamber that it is evenly distributed over the surface of the aggregate and not dumped in one end of the mixing chamber. The asphaltic cement should also be added slowly in a thin sheet the full width of the mixing chamber. If the filler and asphaltic cement are not added in this manner, the time required to produce a uniform paving mixture will be two (2) or more minutes per batch, otherwise, from one (1) to one and one-half (1½) minutes will be sufficient.

(*a*) Wearing Surface. The aggregate for the wearing surface must have a temperature of not less than 275°F. nor more than 350°F. when ready to be coated with the asphaltic cement. The asphaltic cement, when applied to the aggregate, must have a temperature of not less than 250°F. and not more than 350°F., and must be free from unmelted lumps. The mineral filler may be added cold and must be thoroughly dry.

In the preparation of this mixture the aggregate is first added to the mixing chamber, then the mineral filler. After the mineral filler has become uniformly distributed through the aggregate the asphaltic cement is added and the mixing continued until a bituminous mixture is secured that is uniform and homogeneous in composition and all the particles of the aggregate are uniformly and completely coated with the hot asphaltic cement.

(*b*) Binder Course. The aggregate for the binder course must have a temperature of not less than 250°F. nor more than 350°F. when ready to be coated with the asphaltic cement. The asphaltic cement shall have the same temperature when applied as specified for the wearing surface. No mineral filler is required in the binder.

In preparing the binder course, the stone and sand are run into the mixing chamber and the asphaltic cement added as soon as the sand is thoroughly incorporated with the stone. The mixing is continued until all particles of the aggregate are completely coated with hot asphaltic cement and the mixture is uniform and homogeneous in composition. Care must be exercised in the preparation of this binder that the aggregate does not get too hot, that excess fine material or asphaltic cement are not used if rich spots in the binder are to be avoided.

7. Hauling and Handling.

The paving mixtures must be kept clean during hauling and handling and covered during transit with canvas or other materials which will retain their temperature. These mixtures must not be hauled such a distance that segregation of the ingredients takes place or that a crust is formed on the surface, bottom or sides of said mixture which has a temperature lower than that required. These mixtures must not be dumped any faster than they can be properly handled by the shovelers nor at such a rate that over six (6) tons of paving mixture are upon the platforms at the same time. They must be spread immediately after being dumped and must be kept perfectly clean until spread. Any part of the paving mixture which becomes dirty or chilled below the required temperature must be rejected. All paving mixture must be carefully removed from the spot upon which it was placed before any additional paving mixture is placed thereon.

The mixture for the wearing surface, when dumped on the platforms, must have a temperature between 275°F. and 350°F.; for the binder course, between 250°F. and 325°F. Any portions of the wearing surface mixture that become chilled below 250°F. or of the binder below 225°F. before being spread shall be discarded.

These paving mixtures may be dumped direct on a concrete foundation, but when the foundation is macadam or telford they shall be dumped on metal or wooden platforms which must be of such size that the paving mixture will not fall off when dumped thereon or work off during spreading. The wearing surface mixture may be dumped on the binder. However, each load of paving mixture must be dumped outside of the area over which it will be spread.

All vehicles used in transporting paving mixtures must have tight-fitting bottoms which will hold hot, thin mixtures without leaking. When motor trucks are used the bodies should be insulated for long hauls during cold weather so that the paving mixtures adjacent the ends and sides will not become chilled during transit. All motor trucks used for this purpose must have dump bodies that will permit the rapid unloading of these mixtures. The inside surface of these bodies should be oiled just before loading. However, only sufficient of this oil shall be used to coat the surface. No pools of oil must appear on the bottom of the truck.

8. Spreading and Raking.

Immediately after the paving mixture has been dumped upon the platform, it shall be deposited at once upon the foundation or binder with hot shovels in such a manner that any segregation of the ingredients or irregularities in composition will be eliminated as much as possible. After being thus deposited it shall be so spread with hot iron rakes that after being thoroughly compacted by tamping and rolling each course shall have the average thickness, surface finish and contour specified.

During spreading and raking the workmen must not walk over or stand on the paving mixture except when necessary to correct irregularities in the initial raking. The paving mixture shall not be spread any faster than it can be properly handled by the rakers.

(*a*) Binder. The binder course shall only be rolled sufficient to properly compact and bind together the ingredients of the aggregate; also to disclose any open spots or low places. When any depressions are discovered they shall be filled with additional binder and rerolled so that the surface of this binder course shall be of a uniform character, at the required grade and have the specified crown.

The surface of the binder course after compression shall not show in any place an excess of asphaltic cement or fine matrix, and any area of one square foot or more showing an excess of asphaltic cement shall be cut out and replaced with proper binder. Smaller spots may be dried by the use of stone dust and smoothing irons.

After being spread and rolled as above specified the binder course must be protected from all travel and be kept perfectly clean until the top course has been applied. If any part of the binder course shows a lack of bond, becomes loose or broken or gets covered with dirt it must be replaced with proper material, laid in accordance with the requirements given.

The binder course after being properly constructed should be covered immediately with the top course. In no case shall more binder be laid during any one day than can be covered by the top course during the same day. No binder course should be left uncovered during the night. If it becomes coated with dust or dirt when left so uncovered it must be swept clean or replaced with proper material as the Engineer may direct, before any surface course is applied thereto.

(*b*) Surface.—Special care must be used in spreading and raking the wearing surface if porous spots, depression or projections are to be eliminated. For this purpose the Contractor shall employ not less than three (3) rakers for each one hundred (100) square yards of surface pavement laid per hour. Additional rakers must be employed when a greater quantity of pavement is being laid per hour.

The rolling of the wearing surface mixture must be so executed that porous spots will be eliminated, the formation of waves and depressions prevented and the required density and surface finish secured.

Whenever the pavement is laid along side of brick or concrete gutters, street car tracks, man-hole heads or liners, the finished surface adjacent to them shall be left one-quarter ($\frac{1}{4}$) of an inch high in order to provide for subsequent compression by traffic and to avoid depressions which would otherwise be liable to occur at these points.

9. Rolling.

After the paving mixtures have been properly spread and raked they shall be rolled as soon as they will bear the roller without undue displacement or hair cracking. Delays in the initial rolling of the freshly raked mixtures will not be permitted. In all places inaccessible to a roller, such as adjacent to curbs, gutters, headers, man-holes, etc., the required compression shall be secured with hot tampers.

The initial and final rolling of the binder course shall be done with a six (6) to eight (8) ton tandem roller or a ten (10) to twelve (12) ton three-wheel power roller. The initial rolling of the top course or wearing surface shall be done with a five (5) ton tandem roller, but final compression shall always be secured with an eight (8) to ten (10) ton tandem roller or a ten (10) to twelve (12) ton three-wheel power roller when the Engineer permits or requires the use of this type of roller.

When more than one hundred (100) square yards of wearing surface are laid per hour, two (2) rollers shall be kept in use, one of which shall be of the finishing size. An additional finishing roller will be required for each additional one hundred (100) square yards of wearing surface laid per hour. All rollers used shall be kept in good condition and shall weigh not less than two hundred (200) pounds to the inch width of tread. Each roller shall be in the charge of a competent experienced roller Engineer and must be kept in continuous operation as nearly as practicable. During an 8-hour day each roller must be engaged in actual rolling for not less than six and one-half ($6\frac{1}{2}$) hours, not more than one and one-half ($1\frac{1}{2}$) hours being allowed for cleaning fires, watering, etc. The ashes from the roller must not be dumped upon the binder or wearing surface courses.

The surface of the wheels of the roller must be kept clean at all times and either oiled or wet with water as ordered by the Engineer. When the use of water is permitted, it shall not be applied in such quantity that surplus water will run off of the wheels of the roller onto the pavement.

During the initial rolling of both the top and bottom courses, the roller shall travel parallel to the axis of the pavement, beginning at each edge and working towards the center. Each trip of the roller shall overlap the preceding one about one-half ($\frac{1}{2}$) the width of the roller. Alternate trips of the roller should be of slightly different lengths. Subsequent rolling shall be both diagonal and parallel to the axis of the pavement. The rolling shall be continued at the rate of not more than one hundred fifty (150) square yards of wearing surface per hour for each roller of the finishing size. The roller must not pass off the pavement during rolling, nor stand on the completed pavement which has not cooled to normal temperature.

The rolling should be so executed that all parts of the pavement will receive equal compression; also develop any low or high spots caused by improper spreading and raking. The surface of low spots or depressions shall be roughened with a hot rake, additional material added thereto and rerolled immediately. Excess material shall be removed from the high spots. Such repairs should be made as soon after the initial rolling as possible while the pavement is yet fairly soft.

10. Seal Coat.

As soon as possible after the rolling of the mixture is finished and while the surface is yet fresh, clean and hot, a seal coat of bituminous cement shall be spread thereon. The cement used for this purpose shall be the same as used in preparing the pavement mixture. It shall be applied at a temperature between 250°F. and 350°F. from a squeegee distributor, and then evenly spread with rubber squeegees. Only sufficient cement shall be used to coat the surface and fill the surface voids without leaving an excess on the surface. Immediately over this a top dressing of dustless screenings or pea gravel, or a mixture thereof, shall be uniformly spread and rolled into the surface. Some surplus of this dressing shall be left on the surface.

11. Surface Finish.

The surface of the finished pavement must substantially conform to the grade and contour specified and shall be free from depressions or projections which are one-quarter ($\frac{1}{4}$) of an inch above or below the established grade as determined by a straight edge, five (5) feet in length, laid parallel to the axis of the road. It must be uniform in density and composition, thoroughly bonded together and water tight, and be free from porous or rough spots that will remain wet after the balance of the surface is dry. Such portions of the completed pavement as are defective in finish, or that do not comply in all respects with the

requirements of these specifications, shall be taken up, removed and replaced with suitable material, properly made and laid in accordance with the requirements of these specifications at the expense of the Contractor.

12. Joints.

The paving shall be so done that the number of joints required shall be reduced to a minimum. When a rope joint is not used the edges of the previously laid pavement shall be cut off in a straight line far enough back from the edge to insure that the wearing surface has the required thickness. The cut shall be made at a slight angle to the pavement surface and present a smooth unbroken edge. The face of the joint shall be painted with bituminous cement, after which the hot bituminous mixture shall be raked over it to the proper depth. Hot smoothers or tampers shall be carefully employed in such manner as to insure the proper bond between the two (2) paving mixtures without burning or injuring either. The finished joint must be on the same plane as the adjacent finished pavement surface. Joints which are above or below the general plane of the pavement surface must be brought to the proper grade or remade.

The faces of all curbs and gutters, iron castings or other objects projecting through the pavement shall be painted with hot bituminous cement before the adjoining paving mixture is laid. The adjacent paving mixture shall be compressed by ramming with hot tampers when the required compression cannot be secured with the roller.

13. Foundation, Condition of.

The foundation, when a bituminous pavement is applied thereon, must be dry, clean, free from all frost, and have a temperature above 32°F. at the point where the paving mixture is being laid. It must substantially conform to the grade and crown specified, and comply with the requirements given for the type of foundation being used. When a foundation is in the proper condition to receive a paving mixture it must be protected from all travel that will injure, deface or carry foreign material upon it.

14. Edge Protectors.

When the edges of pavements are not protected by a concrete or stone curb or header, four (4) to six (6) inch planks of the same thickness as the finished pavement must be used for this purpose, which shall be firmly secured and left in place until the pavement has been properly rolled and thoroughly set.

15. Construction Season.

The pavement shall be laid between the first day of May and the first day of December, unless written permission is secured from the Department to lay pavement at any other time. No pavement shall be laid when it is raining or when the atmospheric temperature is below 32°F., or when the weather is such as to make it very difficult to lay the paving mixture in a manner which will permit the proper density and surface finish being secured.

16. Workmen.

The workmen employed by the Contractor must have had sufficient experience in the preparation of bituminous paving mixtures and the construction of bituminous pavements to be able to operate the equipment in such a manner that the pavement produced will have the required composition, density and surface finish. The men operating the mixing plant, the spreaders, rakers and roller men must show by the work completed that they have had the necessary experience and are making the proper effort to execute the work in the manner required by these specifications. Otherwise, their services will have to be dispensed with by the Contractor.

17. Plant and Equipment.

The plant used in preparing all bituminous paving mixtures must be of the batch type, capable of mixing in the manner herein specified not less than ten (10) tons of the paving mixture for each mixer per hour, and must be provided with separate chambers for heating and mixing the ingredients. No direct heat except steam shall be applied to the exterior surface of the mixing chamber or flame through the same. The aggregate shall be heated in a revolving kiln. The heat must be so regulated that the aggregate can easily be heated to and maintained at the required temperature. The temperature of the uncoated heated aggregate shall be determined by an electric pyrometer, so placed at the discharge chute of the dryer as to register automatically the temperature thereof.

All mixing plants which do not dry and heat the aggregate in unit batches must be equipped with a twin-pug mixer, rotary screen, storage bins, hopper and scales.

The rotary screen must separate the aggregate into two or more sizes, exclusive of tailings. This screen must be not less than five (5) feet in length and contain the size openings necessary to produce a paving mixture of the composition herein specified.

The main bin into which the hot screened aggregate falls must be divided to correspond to the different sized openings in the rotary screen, and be so arranged that the aggregate from each size screen will pass into its respective bin without getting into the adjacent sub-bins. Each sub-bin must be provided with an overflow that will prevent excess material being accumulated in any one sub-bin. An overflow must also be provided to prevent all material larger than that permitted to be used in the pavement under construction from falling into any of the bins.

Each sub-bin must have a separate outlet with a gate at the bottom, and so arranged that any definite quantity of aggregate can be drawn therefrom. The hopper into which the hot aggregate is drawn must rest upon a set of scales so arranged that any definite weight of material can be weighed out of each sub-bin.

The mixer must be capable of holding and properly mixing at least a one thousand (1,000) pound batch of paving mixture. Each plant, regardless of the type of mixer used, must have at least two asphalt kettles holding not less than six hundred (600) gallons each, and an asphalt thermometer for use therewith. The heat must be applied to these kettles in such a manner that the asphalt cement will be uniformly heated without being burned or decomposed.

The asphalt carrier used to measure and apply the asphalt cement must be balanced upon a set of scales. It shall be so arranged that the asphalt cement can be easily and quickly weighed and poured in a thin sheet between the two lines of paddles the full width of the mixer.

When a squeegee distributor is required to be used, it must be designed for this particular purpose. All equipment and methods used in the preparation and construction of the pavement must be approved by the Engineer before being used on this contract.

18. Field Laboratory.

The Contractor shall provide and keep in good order at the plant the following testing equipment which may be used by the Engineer or Inspector.

1 Penetration Machine Complete with Dishes, Thermometer, Needles, Stop Watch, etc.

1 Laboratory Sand Scale, 500-gr. capacity.

1 Set 6- to 8-in. Sieves, containing the following: Sizes 10, 20, 30, 40, 50, 80 and 200 meshes, with bottom pan and cover.

1 Set 6- to 8-in. Screens, $1\frac{1}{4}$, 1, $\frac{3}{4}$, $\frac{1}{2}$ and $\frac{1}{4}$ in.

2 6-in. Pointed Trowels.

2 6- to 8-in. Steel Spatulas.

2 Brushes.

2 Or more Inspectors' Armor Asphalt Thermometers.

1 Roll Pat Test Paper.

The above equipment must be of standard type and approved by the Testing Engineer. The Contractor shall also provide a field laboratory in which to house and use the above equipment, said laboratory to be not less than ten (10) feet wide, twelve (12) feet long and seven (7) feet high, floored, contain not less than two windows and work bench with the necessary drawers; this laboratory to be used exclusively for testing purposes by the Contractor, Engineer or Inspector.

Surface Type W. B.

75K. WARRENITE-BITULITHIC

Bituminous Concrete

One Course

1. Definition.

A bituminous concrete pavement is defined as one which is composed of clean stone, bituminous sand and a mineral filler, bound together with bituminous cement.

2. Thickness and Weight.

This pavement shall be laid in one course. The completed pavement after the sealing mixture has been blended therewith at the top of the mass must have an average thickness

of not less than two (2) inches after ultimate compression, and shall not be less than one and three-quarter ($1\frac{3}{4}$) inches, nor more than two and one-half ($2\frac{1}{2}$) inches thick at any point, and shall have an average weight of not less than two hundred and fifty (250) pounds per square yard of surface exclusive of any liquid bituminous squeegee coat used.

3. Materials Required.

This pavement shall be prepared from the following ingredients: Trap rock, dolomite or....., bituminous sand, mineral filler and asphaltic cement Grade NA^2, LM^2, CM^2 or.....

These materials shall comply with the requirements given therefor in Articles 92, 95-A and 99.

4. Composition.

The finished pavement, exclusive of any bituminous sealing mixture applied, shall not vary in composition more than the limits given below:

Screens and sieves		Type of openings	Minimum, per cent	Maximum, per cent
Passing	Retained on			
$1\frac{1}{2}$-in.	1-in.	circular	0.0	15.0
1-in.	$\frac{1}{2}$-in.	circular	30.0	50.0
$\frac{1}{2}$-in.	$\frac{1}{4}$-in.	circular	10.0	25.0
$\frac{1}{4}$-in.	10-mesh	square	5.0	15.0
10	30-mesh	square	5.0	15.0
30	80-mesh	square	12.0	22.0
80	200-mesh	square	3.0	8.0
..	200-mesh	square	3.0	8.0
Total stone content—Retained on 10-mesh sieve.....			55.0	75.0
Bitumen content (when stone content is 55.0 to 65.0 per cent.)			6.0	8.0
Bitumen content (when stone content is 65.0 to 75.0 per cent.)			5.5	7.5

5. Estimating Ingredients.

The proportions of the different ingredients required to prepare the pavement shall be determined by weight. The pavement must not vary in composition more than the specified limits given.

The bitumen content is based upon the finished pavement, exclusive of any mineral or bituminous surface coating applied. The exact amount of mineral filler and asphaltic cement to use between the limits defined herein shall be determined by the Testing Engineer. In calculating the percentages of the various sizes of ingredients of which the mineral aggregate is composed, the bitumen is included. The actual amount of paving mixture used shall be estimated from the railroad shipping weights of the ingredients used, batches of paving mixture prepared and used, or loads delivered and laid.

6. Preparation.

The quantity of ingredients used per batch in the preparation of the paving mixture must be accurately determined by either weight or measurement, depending upon the type of plant and kind of material being used. In either case the devices used in measuring these ingredients must be standardized whenever so requested, also the manner in which these devices are used shall be demonstrated and the quantity of material thus secured verified, whenever so ordered by the Inspector or Engineer. The plant used in preparing the paving mixtures shall comply with the requirements given below.

The mineral filler should be so cast into the mixing chamber that it is evenly distributed over the surface of the aggregate and not dumped in one end of the mixing chamber. The asphaltic cement should also be added slowly in a thin sheet the full width of the mixing chamber. If the filler and asphaltic cement are not added in this manner, the time required to produce a uniform paving mixture will be two (2) or more minutes per batch, otherwise, from one (1) to one and one-half ($1\frac{1}{2}$) minutes will be sufficient.

The mineral aggregate, when coated with the bitumen, must have a temperature of not less than two hundred seventy-five (275) degrees F. nor more than three hundred fifty (350) degrees F. The bitumen, when applied to the aggregate, must have a temperature of not less than two hundred fifty (250) degrees F. nor more than three hundred fifty (350) degrees F., and must be free from unmelted lumps.

In preparing the bituminous paving mixture the sand and stone shall first be placed in the mixing chamber, after which the mineral filler shall be added and thoroughly mixed with the sand and stone. The asphaltic cement shall then be added and the mixing continued until a bituminous mixture is secured that is uniform and homogeneous in composition and all the particles of the aggregate are uniformly and completely coated with the hot asphaltic cement. The mineral filler may be added cold, but must be dry.

7. Hauling and Handling.

The paving mixture must be kept clean during hauling and handling and covered during transit with canvas or other materials which will retain their temperature. The mixture must not be hauled such a distance that segregation of the ingredients takes place or that a crust is formed on the surface, bottom or sides of said mixture which has a temperature lower than that required. These mixtures must not be dumped any faster than they can be properly handled by the shovelers nor at such a rate that over six (6) tons of paving mixture are upon the platforms at the same time. They must be spread immediately after being dumped and must be kept perfectly clean until spread. Any part of the paving mixture which becomes dirty or chilled below the required temperature must be rejected. All paving mixture must be carefully removed from the spot upon which it was placed before any additional paving mixture is placed thereon.

The paving mixture when dumped on the platforms must have a temperature between 275°F. and 350°F. Any portions of the mixture that becomes chilled below 250°F. before being spread shall be discarded.

These paving mixtures may be dumped direct on a concrete foundation, but when the foundation is macadam or telford they shall be dumped on metal or wooden platforms which must be of such size that the paving mixture will not fall off when dumped thereon or work off during spreading. However, each load of paving mixture must be dumped outside of the area over which it will be spread.

All vehicles used in transporting paving mixtures must have tight-fitting bottoms which will hold hot, thin mixtures without leaking. When motor trucks are used the bodies should be insulated for long hauls during cold weather so that the paving mixtures adjacent the ends and sides will not become chilled during transit. All motor trucks used for this purpose must have dump bodies that will permit the rapid unloading of the mixture. The inside surface of these bodies should be oiled just before loading. However, only sufficient of this oil shall be used to coat the surface. No pools of oil must appear in the bottom of the truck.

8. Spreading and Raking.

Immediately after a paving mixture has been dumped upon the platform it shall be deposited at once upon the foundation with hot shovels in such a manner that any segregation of the ingredients or irregularities in composition will be eliminated as much as possible.

During spreading and raking the workmen must not walk over or stand on the paving mixture except when necessary to correct irregularities in the initial raking. The paving mixture shall not be spread any faster than it can be properly handled by the rakers.

Special care must be used in spreading and raking the wearing surface and sealing coat mixtures if porous spots, depressions or projections are to be eliminated. For this purpose the Contractor shall employ not less than three (3) rakers for each one hundred fifty (150) square yards of surface pavement laid per hour. Additional rakers must be employed when a greater quantity of pavement is being laid per hour.

Whenever the pavement is laid along side of brick or concrete gutters, street car tracks, man-hole heads or liners, the finished surface adjacent to them shall be left one-quarter (¼) of an inch high in order to provide for subsequent compression by traffic and to avoid depressions which would otherwise be liable to occur at these points.

9. Bituminous Mortar Seal Coat.

The pavement shall be sealed with a hot bituminous mortar, prepared and applied as herein required.

(*a*) *Composition.*

The sealing mixture must be prepared and hauled in the same manner as the paving mixture. It shall be composed of an aggregate similar in character to that used in the main paving mixture, but which will all pass a one-quarter (¼) of an inch screen, and contain from nine (9) to twelve (12) per cent of asphalt cement.

The portion of aggregate passing ten (10) mesh sieve when considered separately from the remainder of the aggregate shall meet the following screen test:

Passing 10-mesh retained on 30-mesh	10	35
Passing 30-mesh retained on 80-mesh	25	50
Passing 80-mesh retained on 200-mesh	15	40
Passing 200	5	15

(*b*) *Application.*

The hot bituminous mortar seal coat shall be applied immediately after the surface paving mixture has been properly spread and raked to the required thickness and grade and before it has had time to cool or has received any compaction which will prevent the essential blending and bonding of the two mixtures. This bituminous mortar shall be spread in a uniform layer, using from thirty (30) to fifty (50) pounds per square yard of surface covered. After being spread, it shall be immediately smoothed off with rakes and additional mortar added on any lean or low spots that appear. After this mortar has been properly spread and raked, the pavement shall be rolled at once and the rolling continued until all roller marks disappear and the surface has the required crown, solidity, density and finish.

10. Rolling.

The rolling shall be done with a ten (10) to twelve (12) ton three-wheel power roller, the wheels of which must be kept clean and oiled at all times. No water shall be applied to the wheels of the roller.

During the initial rolling the roller shall travel parallel to the axis of the pavement, beginning at each edge and working towards the center. Subsequent rolling shall be both diagonal and parallel to the pavement axis. The roller must not pass off the hot paving mixture during rolling nor stand on the completed pavement which has not cooled to normal temperature. Ashes, coal, dirty water or grease must not be allowed to drop from the roller onto the pavement.

If it is found that porous or rough spots appear on the surface of the pavement after rolling the quantity of mortar used must be increased and the raking and rolling so done that these spots will not appear. In case it is found that the pavement adheres to the roller during final rolling, a thin coating of Portland cement shall be sprinkled over the surface to facilitate rolling. However, this Portland cement coating shall not be spread on any place where porous or rough spots appear on the surface.

11. Surface Finish.

The surface of the finished pavements must substantially conform to the grade and contour specified and shall be free from depressions or projections which are one-quarter (¼) of an inch above or below the established grade as determined by a straight edge, five (5) feet in length, laid parallel to the axis of the road. It must be uniform in density and composition, thoroughly bonded together and water tight, and be free from porous or rough spots that will remain wet after the balance of the surface is dry. Such portions of the completed pavement as are defective in finish, or that do not comply in all respects with the requirements of these specifications shall be taken up, removed and replaced with suitable material, properly made and laid in accordance with the requirements of these specifications at the expense of the Contractor. Whenever so ordered by the Engineer a space of twelve (12) inches in width adjacent to the curb shall be coated with hot asphaltic cement which shall be ironed into the pavement with smoothing irons. The cement used for this purpose shall be the same as that used in preparing the paving mixture.

12. Joints.

The paving shall be so done that the number of joints required shall be reduced to a minimum. When a rope joint is not used the edges of the previously laid pavement shall be cut off in a straight line far enough back from the edge to insure that the wearing surface has the required thickness. The cut shall be made at a slight angle to the pavement surface and present a smooth unbroken edge. The face of the joint shall be painted with bituminous cement, after which the hot bituminous mixture shall be raked over it to the

proper depth. Hot smoothers or tampers shall be carefully employed in such manner as to insure the proper bond between the two (2) paving mixtures without burning or injuring either. The finished joint must be on the same plane as the adjacent finished pavement surface. Joints which are above or below the general plane of the pavement must be brought to the proper grade or remade.

The faces of all curbs and gutters, iron castings or other objects projecting through the pavement shall be painted with hot bituminous cement before the adjoining mixture is laid. The adjacent paving mixture shall be compressed by ramming with hot tampers when the required compression cannot be secured with the roller.

13. Foundation, Condition of.

The foundation when a bituminous pavement is applied thereon, must be dry, clean, free from all frost, and have a temperature above 32°F. at the point where the paving mixture is being laid. It must substantially conform to the grade, and crown specified, and comply with the requirements given for the type of foundation being used. When a foundation is in the proper condition to receive a paving mixture it must be protected from all travel that will injure, deface or carry foreign material upon it.

14. Edge Protectors.

When the edges of pavements are not protected by a concrete or stone curb or header, four (4) to six (6) inch planks of the same thickness as the finished pavement must be used for this purpose, which shall be firmly secured and left in place until the pavement has been properly rolled and thoroughly set.

15. Construction Season.

The pavement shall be laid between the first day of May and the first day of December, unless written permission is secured from the Department to lay pavement at any other time. No pavement shall be laid when it is raining or when the atmospheric temperature is below 32°F., or when the weather is such as to make it very difficult to lay the paving mixture in a manner which will permit the proper density and surface finish being secured.

16. Workmen.

The workmen employed by the Contractor must have sufficient experience in the preparation of bituminous paving mixtures and the construction of bituminous pavements to be able to operate the equipment in such a manner that the pavement produced will have the required composition, density and surface finish. The men operating the mixing plant, the spreaders, rakers and roller men must show by the work completed that they have had the necessary experience and are making the proper effort to execute the work in the manner required by these specifications. Otherwise, their services will have to be dispensed with by the Contractor.

17. Plant and Equipment.

The plant used in preparing all bituminous paving mixtures must be of the batch type, capable of mixing in the manner herein specified not less than ten (10) tons of the paving mixture for each mixer per hour, and must be provided with separate chambers for heating and mixing the ingredients. No direct heat except steam shall be applied to the exterior surface of the mixing chamber or flame through the same. The aggregate shall be heated in a revolving kiln. The heat must be so regulated that the aggregate can easily be heated to and maintained at the required temperature. The temperature of the uncoated heated aggregate when screened shall be determined by an electric pyrometer, so placed at the discharge chute of the dryer as to register automatically the temperature thereof.

All mixing plants which do not dry and heat the aggregate in unit batches must be equipped with a twin-pug mixer, rotary screen, storage bins, hopper and scales.

The rotary screen must separate the aggregate into at least four sizes and the openings must vary from a minimum screen opening of about one-tenth ($\frac{1}{10}$) inch to a maximum opening about one and one-fourth ($1\frac{1}{4}$) inch. The openings in the successive screen sections up to one-half ($\frac{1}{2}$) inch size shall not vary more than one-quarter ($\frac{1}{4}$) inch and not more than three-quarter ($\frac{3}{4}$) inch for the sizes larger than one-half ($\frac{1}{2}$) inch.

The effective screening area of each size screen section shall be at least twenty-eight (28) square feet and the screens shall be so arranged that the smallest mesh screen section shall not receive any portion of the aggregate except that which will pass through either the smallest mesh screen or the next larger mesh screen.

The main bin into which the hot screened aggregate falls must be divided to correspond to the different sized openings in the rotary screen, and be so arranged that the aggregate

from each size screen will pass into its respective bin without getting into the adjacent sub-bins. Each sub-bin must be provided with an overflow that will prevent excess material being accumulated in any one sub-bin. An overflow must also be provided to prevent all material larger than that permitted to be used in the pavement under construction from falling into any of the bins.

Each sub-bin must have a separate outlet with a gate at the bottom, and so arranged that any definite quantity of aggregate can be drawn therefrom. The hopper into which the hot aggregate is drawn must rest upon a set of scales so arranged that any definite weight of material can be weighed out of each sub-bin.

The mixer must be capable of holding and properly mixing at least a one thousand (1,000) pound batch of paving mixture. Each plant, regardless of the type of mixer used, must have at least two asphalt kettles holding not less than six hundred (600) gallons each, and an asphalt thermometer for use therewith. The heat must be applied to these kettles in such a manner that the asphalt cement will be uniformly heated without being burned or decomposed.

The asphalt carrier used to measure and apply the asphalt cement must be balanced upon a set of scales. It shall be so arranged that the asphalt cement can be easily and quickly weighed and, in case of twin pug mixer, poured in a thin sheet between the two lines of paddles the full width of the mixer.

When a squeegee distributor is required to be used, it must be designed for this particular purpose. All equipment and methods used in the preparation and construction of the pavement must be approved by the Engineer before being used on this contract.

18. Field Laboratory.

The Contractor shall provide and keep in good order at the plant the following testing equipment which may be used by the Engineer or Inspector.

1 Penetration Machine Complete with Dishes, Thermometer, Needles, Stop Watch, etc.

1 Laboratory Sand Scale, 500-gr. capacity.

1 Set 6- to 8-in. Sieves, containing the following: Sizes 10, 20, 30, 40, 50, 80 and 200 meshes, with bottom pan and cover.

1 Set 6- to 8-in. Screens, $1\frac{1}{4}$, 1, $\frac{3}{4}$, $\frac{1}{2}$ and $\frac{1}{4}$ in.

2 6-in. Pointed Trowels.

2 6- to 8-in. Steel Spatulas.

2 Brushes.

2 Or more Inspectors' Armor Asphalt Thermometers.

1 Roll Pat Test Paper.

The above equipment must be of standard type and approved by the Testing Engineer. The Contractor shall also provide a field laboratory in which to house and use the above equipment, said laboratory to be not less than ten (10) feet wide, twelve (12) feet long and seven (7) feet high, floored, contain not less than two windows and work bench with the necessary drawers; this laboratory to be used exclusively for testing purposes by the Contractor, Engineer or Inspector.

Surface Type A

75L. AMIESITE

Bituminous Concrete

Two Course

1. Definition.

A bituminous concrete pavement is defined as one which is composed of clean stone, bituminous sand and a mineral filler, bound together with bituminous cement.

2. Thickness and Weight.

This pavement shall be laid in two (2) courses; the bottom, or binder course, and the top, or wearing course, in the ratio of not less than two (2) nor more than three (3) parts of bottom course as one (1) part of top, by weight. The finished pavement must be not less than two (2) nor more than three (3) inches thick at any point after ultimate compression, and weigh not less than two hundred and fifty (250) pounds per square yard of surface. The thickness of the top course must be sufficient to completely cover the bottom course, and also to eliminate any inequalities in the binder surface. However, in no case shall it be laid over one (1) inch thick after compression.

3. Materials Required.

The pavement shall be prepared from the following ingredients: trap rock, dolomite or ....., and stone dust, Grade A, hydrated lime, and bituminous cement, Grade NA^3, LM^3, T^3, CM^3, or.....

These materials shall comply with the requirements therefor as defined in Articles 92 and 99.

4. Composition.

The finished pavement must not vary in composition more than the limits given below:

Screens and sieves		Type of openings	Bottom course		Top course	
Passing	Retained on		Minimum, per cent	Maximum, per cent	Minimum, per cent	Maximum, per cent
2-in.	1-in.	Circular	40.0	70.0		
1-in.	½-in.	Circular	25.0	35.0	....	20.0
½-in.	¼-in.	Circular	0.0	10.0	40.0	55.0
¼-in.	10-mesh	Square	3.0	8.0	15.0	30.0
10	30-mesh	Square	4.0	8.0	8.0	15.0
30	80-mesh	Square	3.0	6.0	3.0	8.0
80	200-mesh	Square	2.0	7.0	2.0	6.0
200-mesh	Filler	Square	2.0	6.0	4.0	8.0
Total stone content—retained on 10-mesh			70.0	95.0	65.0	85.0
Bitumen content.....			3.0	5.0	5.5	8.0

5. Estimating Ingredients.

The proportions of the different ingredients required to prepare the pavement shall be determined by weight. The pavement must not vary in composition more than the specified limits given.

The bitumen content is based upon the finished pavement, exclusive of any mineral or bituminous surface coating applied. The exact amount of mineral filler and asphaltic cement to use between the limits defined herein shall be determined by the Testing Engineer. In calculating the percentages of the various sizes of ingredients of which the mineral aggregate is composed, the bitumen is included. The actual amount of paving mixture used shall be estimated from the railroad shipping weights of the ingredients used, batches of paving mixture prepared and used, or loads delivered and laid.

6. Preparation.

The quantity of ingredients used per batch in the preparation of the paving mixture must be accurately determined by either weight or measurement, depending upon the type of plant and kind of material being used. In either case the devices used in measuring these ingredients must be standardized whenever so requested, also the manner in which these devices are used shall be demonstrated and the quantity of material thus secured verified, whenever so ordered by the Inspector or Engineer. The plant used in preparing the paving mixtures shall comply with the requirements given below.

The mineral filler should be so cast into the mixing chamber that it is evenly distributed over the surface of the aggregate and not dumped in one end of the mixing chamber. The asphaltic cement should also be added slowly in a thin sheet the full width of the mixing chamber. If the filler and asphaltic cement are not added in this manner, the time required to produce a uniform paving mixture will be two (2) or more minutes per batch, otherwise, from one (1) to one and one-half (1½) minutes will be sufficient.

The mineral aggregate must be perfectly dry when coated and have a temperature of not less than 60°F. nor more than 125°F. The bitumen, when applied to the aggregate, must have a temperature of not less than 250°F. nor more than 350°F., and must be free from

unmelted lumps. From three (3) to five (5) pounds of hydrated lime shall be used for each ton of paving mixture prepared.

In preparing the paving mixture for both the top and bottom courses, the stone and sand shall first be placed in the mixing chamber, after which some liquefier shall be added, and as soon as the aggregate is coated therewith the asphaltic cement shall be added. More liquefier shall then be added and the mixing continued until the aggregate is completely coated with the asphaltic cement. The hydrated lime shall then be added, and more liquefier, if necessary, to secure the proper distribution of the asphaltic cement. The mixing shall continue until all particles of the aggregate are completely and uniformly coated with the asphaltic cement.

The paving mixture, when properly prepared, must be uniform in composition, free from lumps or balls containing an excessive quantity of bitumen, from material containing less bitumen than that required, and not show evidence of the improper application of the liquefier. The above mixture shall not be laid sooner than twenty-four (24) hours nor later than fourteen (14) days after preparation, unless written permission is secured from the Engineer to lay the same before or after these intervals.

7. Hauling and Handling.

The paving mixtures must be kept clean during hauling and handling. These mixtures must not be dumped any faster than they can be properly handled by the shovelers, nor at such a rate that over six (6) tons of paving mixture are upon the platforms at the same time. They must be spread immediately after being dumped, and must be kept perfectly clean until spread. Any part of the paving mixture which becomes dirty must be rejected. All paving mixture must be carefully removed from the spot upon which it was placed before any additional paving mixture is placed thereon.

These paving mixtures may be dumped direct on a concrete foundation, but when the foundation is macadam or telford they shall be dumped on metal or wooden platforms, which must be of such size that the paving mixture will not fall off when dumped thereon or work off during spreading. The wearing surface mixture may be dumped on the binder. However, each load of paving mixture must be dumped outside of the area over which it will be spread.

All vehicles used in transporting paving mixtures must have tight-fitting bottoms which will hold hot, thin mixtures without leaking. When motor trucks are used the bodies should be insulated for long hauls during cold weather so that the paving mixtures adjacent the ends and sides will not become chilled during transit. All motor trucks used for this purpose must have dump bodies that will permit the rapid unloading of the mixture. The inside surface of these bodies should be oiled just before loading. However, only sufficient of this oil shall be used to coat the surface. No pools of oil must appear in the bottom of the truck.

8. Spreading.

(*a*) *Bottom Course.*

The paving mixture for both courses must have a temperature of not less than 50°F. nor more than 125°F., when dumped on the platforms or when spread, unless written permission is secured from the Engineer to lay the paving mixture when it has a lower or higher temperature than that specified above.

The bottom course shall be so spread upon the foundation that after being rolled as herein specified, it will be uniform in density and its upper surface will have the proper crown and be parallel to the grade established for the surface of the finished pavement.

The time and manner of rolling shall be governed by the condition of the paving mixture. If the paving mixture contains enough liquefier to be soft and plastic it shall not be rolled until the bitumen has hardened sufficiently to give the pavement the necessary stability when properly consolidated by rolling. During rainy or cold weather it may require twenty-four (24) hours or more for the bitumen to cure after the paving mixture has been spread, but during hot, dry weather it may cure sufficiently in from six (6) to eight (8) hours.

When properly cured the paving mixture shall be rolled. The initial rolling shall be continued until the desired bond between the ingredients of the aggregate is secured and any porous or low spots disclosed. Depressions made by rolling shall be filled with additional material and rerolled so that the surface of this bottom course will be of a uniform character and have the required grade and crown.

After being spread and rolled as above specified, the bottom course must be protected from all travel and kept perfectly clean until the top course has been applied. If any part of this course shows a lack of bond, becomes loose or broken up, or covered with mud, it must be replaced with proper material laid in accordance with the requirements given herein. If, before the surface course is applied, it becomes coated or partly coated with dust, the part thus coated must be swept and then give a light application of bituminous cement Grade K, or replaced with proper material as the Engineer may direct. When this bituminous cement is used it must be allowed to cure before any surface course is applied to the bottom course thus coated. If the bottom course becomes wet before it can be covered, it must be allowed to dry before the surface pavement is laid.

(*b*) *Top Course.*

After the bottom course has been spread and rolled as above specified it shall be covered at once with the top course. This course shall be spread in a uniform layer and immediately rolled until it shows no further evidence of compressibility.

9. Rolling.

The initial and final rolling shall always be done with 10- to 12-ton three-wheel power-driven roller, or a 12- to 15-ton tandem roller. During the initial rolling the roller shall travel parallel to the axis of the pavement, beginning at each edge and working towards the center.

Subsequent rolling shall be both diagonal and parallel to the axis of the pavement. The rolling shall be continuous at the rate of not more than one hundred fifty (150) square yards of surface per hour for each roller. The roller must not pass off the paving mixture during rolling and the wheels of the same must be kept clean and oiled at all times. No water shall be applied to the wheels of the roller. Ashes, coal, dirty water or grease must not be allowed to drop from the roller onto the pavement.

If porous spots or spots showing compression remain after rolling, more of the top course must be added at such points and firmly rolled into place. After rolling has been finished the surface of the top course must have the required crown, density and thickness and be at the grade established for the surface of the finished pavement. The surface shall then be covered with a thin coating of clean, coarse sand or stone dust, using about five (5) pounds per square yard. After this coating has been applied, the part of the pavement thus covered must be open to travel.

The faces of the curbs, gutters, iron castings and other objects in the pavement shall be painted with bituminous cement Grade K before the above mixture is placed against them. The adjacent paving mixture shall be compressed by tamping when it is impossible to properly compress it by rolling.

10. Surface Finish.

The surface of the finished pavement must be even, uniform, free from bumps, waves or depressions that are more than one-quarter (¼) of an inch below or above the general surface of the pavement as determined by a straight edge not less than five (5) feet in length, laid parallel to the axis of the pavement. It must be uniform in density and composition, thoroughly bonded together, water-tight. and have the grade and crown specified or shown on plans. The paving mixture must be so spread, raked and rolled that the pavement surface will be free from porous or rough spots. When such spots appear in the surface they must be repaired in a manner satisfactory to the Engineer or cut out and replaced with material prepared and laid as herein specified.

Portions of the completed pavement which are defective in finish, compression or composition, or which do not comply in all respects with the requirements of these specifications, at the Contractor's expense shall be removed, and replaced with material prepared and laid in accordance with the requirements therefor as given herein.

11. Foundation, Condition of.

The foundation, when a bituminous pavement is applied thereon, must be dry, clean, free from all frost, and have a temperature above 32°F. at the point where the paving mixture is being laid. It must substantially conform to the grade and crown specified, and comply with the requirements given for the type of foundation being used. When a foundation is in the proper condition to receive a paving mixture it must be protected from all travel that will injure, deface or carry foreign material upon it.

12. Edge Protectors.

When the edges of pavements are not protected by a concrete or stone curb or header, four (4) to six (6) inch planks of the same thickness as the finished pavement must be used

for this purpose, which shall be firmly secured and left in place until the pavement has been properly rolled and thoroughly set.

13. Construction Season.

The pavement shall be laid between the first day of May and the first day of December, unless written permission is secured from the Department to lay pavement at any other time. No pavement shall be laid when it is raining or when the atmospheric temperature is below 32°F., or when the weather is such as to make it very difficult to lay the paving mixture in a manner which will permit the proper density and surface finish being secured.

14. Workmen.

The workmen employed by the Contractor must have sufficient experience in the preparation of bituminous paving mixtures and the construction of bituminous pavements to be able to operate the equipment in such a manner that the pavement produced will have the required composition, density and surface finish. The men operating the mixing plant, the spreaders, rakers and roller men must show by the work completed that they have had the necessary experience and are making the proper effort to execute the work in the manner required by these specifications. Otherwise, their services will have to to be dispensed with by the Contractor.

15. Plant and Equipment.

The plant used in preparing the bituminous paving mixtures must be of the batch type, capable of mixing in the manner herein specified, not less than ten (10) tons of the paving mixture each mixer per hour, and must be provided with separate chambers for drying and mixing the ingredients. No direct heat except steam shall be applied to the exterior surface of the mixing chamber. The aggregate, when drying is required, shall be heated in revolving kilns. The heat must be so regulated that the aggregate can easily be heated to, and maintained at, the required temperature.

All mixing plants must be equipped with a twin-pug mixer, rotary screen, storage bins, hopper and scales. The screen must contain the size openings necessary to produce a paving mixture of the composition specified.

The mixer must be capable of holding and properly mixing at least a 1,000-lb. batch of paving mixture. Each plant, regardless of the type of mixer used, must have at least two asphalt kettles holding not less than six hundred (600) gallons each, and an asphalt thermometer for use therewith. The heat must be applied to these kettles in such a manner that the asphaltic cement will be uniformly heated without being burnt or decomposed.

The asphalt carrier used to measure and apply the asphaltic cement must be balanced upon a set of scales. It shall be so arranged that the asphaltic cement can be easily and quickly weighed and poured in a thin sheet between the two lines of paddles and for the full width of the mixer.

When a squeegee distributor is required to be used it must be designed for this particular purpose. All equipment and methods used in the preparation and construction of the pavement must be approved by the Engineer before being used on this contract.

16. Field Laboratory.

The Contractor shall provide and keep in good order at the plant the following testing equipment which may be used by the Engineer or Inspector.

1 Penetration Machine complete with Dishes, Thermometer, Needles, Stop Watch, etc.

1 Laboratory Sand Scale 500-gr. capacity.

1 Set 6- to 8-in. Sieves, containing the following: Sizes 10, 20, 30, 40, 50, 80, and 200 meshes, with bottom pan and cover.

1 Set 6- to 8-in. Screens, 1¼, 1, ¾, ½ and ¼ in.

2 6-in. Pointed Trowels.

2 6- to 8-in. Steel Spatulas.

2 Brushes.

2 Or more Inspectors' Armor Asphalt Thermometers.

1 Roll Pat Test Paper.

The above equipment must be of standard type and approved by the Testing Engineer. The Contractor shall also provide a field laboratory in which to house and use the above equipment, said laboratory to be not less than ten (10) feet wide, twelve (12) feet long and seven (7) feet high, floored, contain not less than two windows and work bench with the necessary drawers; this laboratory to be used exclusively for testing purposes by the Contractor, Engineer or Inspector.

BRICK PAVEMENTS

All readers are familiar in a general way with the character of brick pavements; they are merely specially hard well-manufactured brick set on either a cement sand, bituminous sand or sand cushion and the joints between the brick filled with cement grout, bituminous filler or in unusual conditions plain sand. The foundation for the brick surfaces is generally cement concrete ranging in depth from 5 to 8 in. In some cases, firm macadam foundations can be utilized to advantage in place of the cement concrete base. Specifications, page 370, describe construction operation in detail.

FIG. 141.—Modern rural brick highway. State of Ohio.

Brick pavements are satisfactory for the heavier Class I traffic roads. They have been used extensively for city pavements and for a considerable mileage of primary State Highways. The economy of their use depends largely on the location of the road in relation to the brick manufacturing plant as the item of freight has of late years been the cause of a serious curtailment of the use of this type. There have been cases where brick roads close to brick plants cost about as much as at greater distances but this is an artificial condition due to lack of competition and manipulation of sale price which is liable to develop with any material. Well-manufactured paving brick is an excellent surfacing material as the pavement is pleasing in appearance having a warm neutral tone; it is a safe surface for high-speed travel; it absorbs very little moisture and has no tendency to push into humps or waves. For rural

highway conditions, however, the initial cost is usually so much higher than other acceptable types that it is rarely selected on the score of economy under moderate traffic and where it is used (largely for portions of rural roads passing through village business streets) the selection is based on the factors of extremely heavy traffic, appearance and local preference for the type. It seems a pity that such an excellent material has been so badly handicapped by freights and by an adherence to a form of brick which may perhaps be modified to advantage for rural highway conditions. The size of the highway program ahead of us demands the use of all available materials and clay products are so widely distributed that it seems ridiculous not to make more use of this excellent material. Some attempts have been made to modify brick pavement practice to make it more applicable for the ordinary rural road. These attempts have not been entirely successful but show sufficient promise to warrant more serious consideration of modifications in practice. One method is described on page 382.

Standard brick pavements including base cost for initial construction from $3.50 to $4.50 per square yard 1922 cost conditions; the yearly maintenance has a wide range due to all sorts of conditions but probably falls between $0.003 to $0.04 (0.015 average) per square yard. The cost of surface renewal distributed over the life of the pavement is probably about $0.10 to $0.16 per square yard per year for rural highway conditions on primary roads carrying over 4,000 vehicles daily.[1] A reasonable surface life for heavy traffic roads constructed of this type is probably about 12 to 18 years although there are many cases which do not fall within these limits (see Chap. IV).

There are three general types of brick pavement.

1. Monolithic base and top with cement grout joint filler.

2. Semi-monolithic type with cement-concrete base, cement sand or bituminous sand cushion and either cement grout or bituminous joint filler.

3. "Rolled Base" with some type of macadam or gravel base surfaced with brick having either bituminous or cement grout joint filler.

The Monolithic Type is constructed by laying the brick on the green concrete base having a skim coat of cement sand before the base has set; in this way a fairly good bond between base and top course of brick is obtained. The basic idea of this construction was to produce a monolithic slab and by this means reduce the necessary depth of concrete base. It has not proved as effective as its originators hoped. The Semi-monolithic is the best known construction; it depends largely for its strength on the concrete base; which is constructed and allowed to set before the surface is constructed. On this base an evener cushion

[1] These renewal costs are based on a maximum permissible vialog rating of 250″ per mile without excessive ordinary maintenance charges.

of sand or a mixture of sand and cement or bitumen and sand is spread, and the brick surface laid and filled with either cement grout or bitumen. The "rolled base" type is essentially the same as the Semi-monolithic except that macadam or gravel is substituted for the cement concrete base.

In the author's opinion the monolithic type should be used with caution, in northern climates at least, as it does not seem to meet conditions as well as the second class. The rolled base type should be used with caution under extremely heavy traffic and even under moderate traffic it has some disadvantages due largely to the shape of the standard block. The best type of brick pavement appears to be the second class noted above.

If the second class (Semi-monolithic) is used, there is considerable disagreement between engineers in regard to the use of cement sand cushion as against bituminous sand cushion and in regard to the use of cement grout filler as against bituminous mastic filler. Assuming that the base is strong enough to prevent failure due to weakness of the pavement and that the brick are uniformly well manufactured and stand the traffic pounding, the surface defects which develop are due either to temperature cracking or blow-ups or spauling at joints. Cracking and blow-ups are reduced by the use of bituminous filler in place of grout filler; joint spauling is reduced by the use of cement grout filler. Excellent pavements can be constructed by either method. In villages where appearance is a large factor, and where it may be necessary to take up areas of pavement, the author personally favors the cement-sand cushion with bituminous joint filler. On rural highways outside of villages where appearance is not such a large factor, the author prefers the cement-sand cushion with cement grout filler as while a small percentage of cracks will occur, the pavement is not seriously damaged and its riding quality for high-speed traffic is bettered. Recent tests on the Bates Road (1922) seem favorable to the bituminous-sand cushion (see Appendix D, page 601).

Considering the fact that brick surfaces are an expensive type which can only be economically justified under heavy traffic, it is most certainly desirable to use only the best of materials in the construction. The depth of the base should be amply strong when first constructed as it is poor policy to take a chance on depth failure for this type. Materials, details of design and inspection are outlined on page 361.

Brick paving practice is going through a transition stage in the same way as concrete paving practice due to the radical difference in service demanded by modern motor traffic on rural highways as contrasted with the old horse-drawn vehicles and any statement of recommended practice is tentative at best.

Recommended Designs.—The following designs can be used with assurance of reasonable success. They represent conservative practice for localities having a gross vehicle load limitation of 28,000 lb.

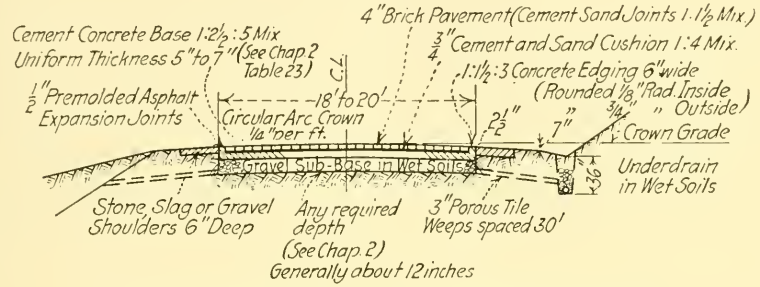

4"Brick Pavement(Cement Sand Joints 1:1½ Mix.)
Cement Concrete Base 1:2½:5 Mix
Uniform Thickness 5"to 7"(See Chap 2 Table 23)
¾"Cement and Sand Cushion 1:4 Mix.
1:1½:3 Concrete Edging 6"wide
(Rounded ⅛"Rad. Inside
¾" " Outside)
½"Premolded Asphalt Expansion Joints
18'to 20'
Circular Arc Crown
1a"per ft.
2½"
7"
Crown Grade
Gravel Sub-Base in Wet Soils
Underdrain in Wet Soils
Stone, Slag or Gravel Shoulders 6"Deep
Any required depth (See Chap. 2)
3"Porous Tile Weeps spaced 30'
Generally about 12 inches

Fig. 142*A*.—Recommended design (cement grout joints).

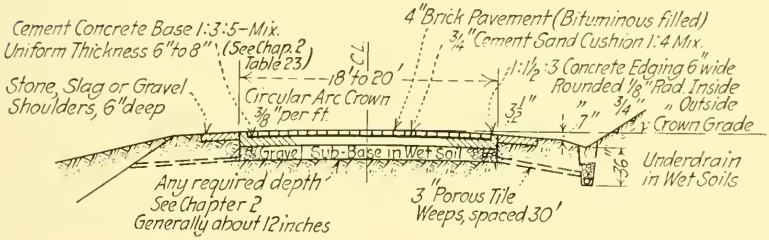


Fig. 142*B*.—Recommended design (bituminous joints).

Suitable Materials.—Suitable materials for macadam and cement bases are the same as discussed under Macadam Pavements, pages 207 to 209 and under Asphaltic Concrete Pavements, page 301.

Brick. (*Size.*)—The size of standard paving block is usually specified as between 3¼ in. wide, 3¾ in. deep × 8½ in. long and 3½ in. wide × 4 in. deep × 9 in. long. For any particular size used on single jobs, the maximum difference in depth should not exceed ⅛ in., in width ⅛ in. and in length ½ in. Kiln marks over 3/64 in. in height cause the rejection of individual brick. If the brick have rounded edges, they should not exceed 3/16-in. radius (square brick are preferable where a cement grout filler is specified). Wire cut or pressed lugs on one side of the brick should produce a separation of the block of at least ⅛ in. and not over ¼ in. This standard size produces a very effective and handsome pavement on village or city streets and on Class I traffic rural highways. There is, however, a growing need for a smaller unit for resurfacing worn out macadam and concrete pavements particularly on grades of more than 4 per cent where asphaltic concrete pavements are not entirely satisfactory on account of tendency of motors to skid in damp weather. Whether this need will be met by small stone blocks or by brick cubes is still in doubt and will depend very largely on the general attitude of the

stone block and brick paving manufacturers in producing an acceptable grade of cube at a reasonable cost. The standard 4-in. block is not only very costly for such conditions but also introduces too much change in surface elevation particularly where a contracted section in cut with gutters is used.

A considerable yardage of pavement constructed of brick of standard surface dimensions but with a 3-in. depth has been laid in an effort to reduce freight costs on the materials. There is considerable doubt as to the advisability of reducing depth dimension where the width and length remain the same as it unbalances the resistance of the block particularly over a macadam base and for heavy traffic roads this expedient may well be used with caution. Special shaped grooved block known as hillside brick are used on steep grades.

Quality.—Paving block are manufactured of special mixtures of clay or shale. Most pavers are a shale product although very good brick can be manufactured by a well-controlled clay mixture. The essential qualities of the finished product are that the brick shall be well annealed, tough and evenly burned and free from laminations, voids and cracks. When broken, they must show a uniform stonelike fracture. There are two general types, the wire cut brick and the repressed brick. The concensus of opinion among engineers seems to favor the wire cut method as the brick is, perhaps, less likely to show laminations. The wire cut block also has the square edge which is desirable where cement grout is used as the joint filler on account of less liability for the grout to chip out.

Where bituminous joint filler is used, a well-manufactured repressed brick with rounded edges is very satisfactory.

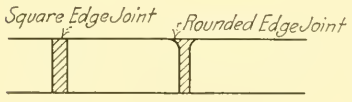


FIG. 143.—Typical joints.

All pavers are subject to tests for toughness and absorption and in some cases to the rupture test for cross-breaking although the last test is hardly necessary for the standard size block. Toughness is determined by the rattler test described in Appendix A. The maximum loss by abrasion in this test is usually set at 24 per cent for heavy traffic roads and the maximum absorption at $3\frac{1}{2}$ per cent. Modulus of rupture is to be not less than 2,000 lb. per square inch computed by the formula $R = 3\frac{WL}{2bd^2}$ in which

R = Modulus of rupture.
W = Load in pounds which produces rupture.
L = Length between supports (6 in.).
b = Width of brick in inches.
d = Depth of brick in inches.

Cushion Sand.—The plain sand cushion is going out of use in favor of either the cement sand or bituminous sand cushion. Where a sand cushion is used, it must be free from pebbles and fairly clean. A common specification calls for 100 per cent passing a 6 sieve; 90 per cent passing a 20 sieve and not over 10 per cent of loam or silt. Unsatisfactory portions of many brick pavements have been directly traceable to poor cushion and to careless manipulation which resulted in the sand working up between the brick and preventing proper grout penetration.

Where the cement sand cushion is used, a first class concrete sand containing not over 8 per cent of loam is required; the usual mix for this type of cushion is 1 part cement to 4 of sand which gives the necessary stiffness to prevent flowing of the cushion.

Where bituminous sand cushion is used, the sand should be a clean coarse concrete and mixed with about 4 to 6 per cent of bitumen of the proper grade (see Appendix D).

Grout Sand.—Must be a clean sharp concrete sand containing not over 5 per cent of loam or silt. A common specification requires 100 per cent passing a 12 sieve and not over 40 per cent passing a 50 sieve. A mixture of 1 part cement to 1 part grout is often specified. The National Brick Manufactures recommend 1 part cement to 1½ parts sand.

Bituminous Filler.—Either asphalt or tar pitch filler can be successfully used for Specifications, see Appendix A, page 561.

Amounts of Materials.—The amounts of material for macadam bases are given under Macadam, page 209, and for Concrete Bases, page 305.

Brick is usually purchased by the square yard finished pavement on account of culling, etc. so that the number of brick per square yard is of little value; in case brick is purchased by the 1,000, the following table from Blanchard will be of use. Ordinary standard paving block 3½ × 4 × 9 in. lay about 40 to the square yard.

Size of brick [1]	Number of brick per square yard ½-in. joint
2¼ × 8 × 4 laid flat	67
2¼ × 8¼ × 4 laid edgewise	65
3¼ × 8½ × 4 laid edgewise	45
2½ × 8½ × 4 laid edgewise	57
3 × 9 × 4 laid edgewise	46

[1] BLANCHARD, "Highway Engineering."

Grout.—One barrel of cement will grout approximately 36 sq. yd. of standard 4-in. depth block with grout mixed 1 to 1.

Expansion Joints.—Premoulded joints purchased by the linear foot are usually used. In case the joints are poured, 1 bbl. of paving pitch will fill approximately 130 lin. ft. of joint 1 in. wide and 4 in. deep.

DESIGN

Design covers selection of type of pavement (Monolithic, Semi-monolithic or Rolled Base), Depth of Base, Type of Brick Surface (Grouted or Bituminous filled), Type of Cushion (Cement Sand, Bituminous Sand or Plain Sand), Width and Crown of Pavement.

Type.—As previously discussed, the semi-monolithic on cement concrete base is the type probably entitled to most consideration for heavy traffic rural highways.

Depth of Base.—If a macadam base is used, the design of depth is quite definite as discussed in Chap. II. If the cement concrete type of base is used, any existing formula is speculative to say the least and experience is the best guide. Experience can, however, be expressed in the form as tentative formulae as developed in Chap. II, pages 132 to 137.

Adequate depths of macadam base under heavy traffic depend on the foundation soil and range from 8 to 24 in. using Formula 2, page 93,

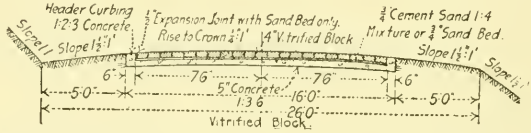


FIG. 144*A*.—Standard brick pavement. State of Pennsylvania (1922).

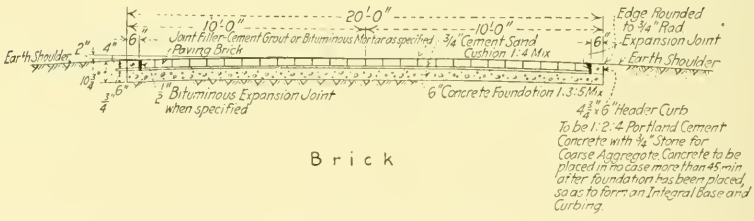

10'-0"
20'-0"
10'-0"
Edge Rounded to ¾" Rad
Earth Shoulder
2"
4"
6"
Paving Brick
Joint Filler-Cement Grout or Bituminous Mortar as specified
¾" Cement Sand Cushion 1:4 Mix
6"
Expansion Joint
Earth Shoulder
10½"
6"
½" Bituminous Expansion Joint when specified
6" Concrete Foundation 1:3:5 Mix
4½"
6" Header Curb
To be 1:2:4 Portland Cement Concrete with ¾" Stone for Coarse Aggregate. Concrete to be placed in no case more than 45 min. after foundation has been placed, so as to form an Integral Base and Curbing.
Brick

FIG. 144*B*.—Standard brick pavement. State of New Jersey (1922).

with a design wheel load of 14,000 lb. (28,000-lb. gross static vehicle load) and assuming that a bituminous filled brick top is equivalent to 2 in. of macadam.

Adequate depths of cement concrete bases depend on the richness of the mix of the concrete base, on whether the pavement is the monolithic or semi-monolithic type and if the semi-monolithic type whether the surface is grout filled or has a bituminous filler. Current practice generally uses a 4-in. depth of cement concrete with 4-in. brick for the monolithic type and for the semi-monolithic type with concrete ranging in mix from 1:3:6 to 1:2:4, the depth of base ranges from 5 to 8 in. with slightly greater depth for bituminous filled brick. Tentative formulae developed in Chap. II indicate that for rural highway conditions (28,000-lb. gross vehicle load) using the recommended semi-monolithic type with a base

mix of 1:2½:5 a depth of 6 to 7 in. for grout filled surface and 7 to 8 in. for bituminous filled surface will be satisfactory.

Expansion and Contraction.—Bituminous filled brick surfaces do not require any special provision for temperature stresses.

Cement grout filled brick require longitudinal joints along curb or edging. Premoulded bituminous strips are the best type of joint. A joint width on each side of ½ in. is sufficient for rural roads up to 20 ft. For wider streets 20 to 30 ft. ¾-in. width and for greater widths 1 in.

Transverse joints are rarely used and appear to be detrimental; infrequent blow-ups may better be permitted. Where they are used, they are generally spaced at 50-ft. intervals and have a ½ in. thickness.

Width and Crown.—Widths are the same as for any rigid rural pavement (pages 70 and 71). Widening on curves is desirable. Where a state highway with a large volume of traffic passes through villages 30 ft. is satisfactory for resident streets and 40 to 60 ft. for business streets. The crown usually used for 18- to 20-ft. rural roads is a circular arc ¼ in. per foot for grouted brick and ⅜ in. per foot for bituminous filled; banking on curves is given, page 211. Village street crowns are indicated, page 604. The straight line crown is to be avoided as discussed page 274 (Concrete Pavements).

Steep Grades.—Hillside brick should be used on grades over 5 per cent for grouted surfaces and on grades over 8 per cent for bituminous filled brick where horse traffic must be considered.

Equipment.—Ordinary construction equipment previously described applies to grading, culverts and concrete base. Special equipment for economically handling the brick surface work requires the possible use of conveyors in unloading and laying brick and a small grout mixer. The rollers used for the brick surface are the tandem type and generally weigh about 3 tons. A hand roller similar to the ordinary lawn roller about 2½ ft. wide and about 2½ ft. in diameter with water ballast is a convenient tool for compacting sand cushion preliminary to striking.

Inspection Details.—The success of a brick pavement depends largely on the care in construction and rigid inspection is necessary. Inspection covers careful control of grading; culvert back-fills; concrete base and brick surface. Inspection methods for all operations up to the brick surface have been previously discussed.

Brick surface inspection includes control of handling brick; cushion; laying; culling; rolling; grouting and protection until set. Suggestions published by the Dunn Wire Cut Lug Brick Co. are as definite and reliable as any source. They are quoted as follows:

Expansion Joints.—Expansion joints shall be placed parallel with and at each curb line and extend across each street and alley intersections. It should be one-half (½) in. in width for streets less than twenty (20) ft. wide; three-fourths (¾) in. for streets from twenty (20) to thirty (30)

ft. wide, and one (1) in. in width for streets wider than thirty (30) ft. This joint must extend to the depth of the brick.

A premolded or prepared bituminous strip which will be unaffected by the action of water and will remain pliable at all temperatures to which it may be subjected shall be used for this purpose. The material should be made into strips of suitable length and of the required depth and thickness and shall be placed in the pavement with the ends closely joined as the bricks are being laid.

Delivery of Brick.—Before the grading is finished the brick shall be hauled and neatly piled outside the curb line in sufficient quantities to complete the brick surface. Clamps or conveyors may be used in connection with this work, but the brick shall not be dumped from wagons to piles, or from cars to wagons, nor shall they be piled in any location where they are likely to become bespattered or covered with mud or otherwise injured, unless thoroughly protected.

In delivering the brick from the piles for placement in the street, no wheeling in barrows will be allowed on the brick surface. The brick shall be so arranged and carried on a pallet, or conveyor, that when delivered to the dropper each brick, in the regular operation of placing upon the cement-sand bed as prepared, will naturally lie with the projections in the same direction and with the best edge uppermost.

Cement-sand Bed.—Upon the foundation as prepared there shall be spread a bed of cement and sand of uniform density to the depth of one (1) in. and in the proportion of one cement and four sand. The cement and sand shall be thoroughly mixed dry in a mixer until a uniform color is obtained.

The cement-sand bed shall be carefully shaped to a true cross-section, parallel with the finished pavement, by means of a template covering at least one-half (½) of the width of the brick work, and so made as to be easily drawn over the curb or guide rails set to the proper elevation. The operation of shaping the cement-sand bed for the brick is considered of prime importance in securing the desired evenness in the surface of the finished pavement.

Brick Laying.—Upon the cement-sand bed as prepared the brick shall be immediately laid with the best edge up, the projections in one direction, and with the courses straight and at right angles to the center line of the pavement, except in the case of hillside brick which are to be laid parallel thereto. All joints must be broken at least three (3) inches; and the courses straightened by tapping lightly with a sledge on a four by four inch timber three (3) feet in length, provided for that purpose. Nothing but the whole brick shall be used except in starting and finishing courses, or in such cases as may be directed by the engineer. The cutting and trimming of the brick shall be done by experienced men. For closures, nothing less than three (3) inch bats shall be used; and the

fractured ends laid towards the center of the pavement. Broken and chipped brick suitable for batting shall be used so far as practical in obtaining the necessary half brick for breaking course and making closures, instead of breaking otherwise whole and sound brick. All brick when laid shall be clean and kept clean and entirely free from dirt or other foreign matter until the pavement is completed. All the work of brick laying shall be done over the brick already laid. The disturbing of the prepared cement-sand bed is prohibited. As soon as any surplus of delivery of brick is ascertained, they shall promptly be moved forward for use.

After the brick have been laid, the chips shall be swept from the street, all soft brick removed, and those badly broken, badly spawled or misshapen shall be turned over or removed by the contractor. Brick slightly chipped for batting in, shall be carried forward and used for that purpose; the remainder shall be placed in separate piles along the street. The inspector shall keep the brick culled and the contractor shall make the necessary changes and replacements so that the work at all times shall be ready for the grouting within fifty (50) feet of the brick laying.

Rolling.—Immediately after the brick in the pavement have been inspected and the surface of the pavement swept clean, it shall be rolled with a self-propelling tandem roller, weighing approximately three (3) tons, in the following manner: The rolling will commence near the curb or edging line, at a slow pace and continue back and forth until the center of the pavement is reached, then pass to the opposite curb or edging line and repeat in the same manner to the center of the street. After the first passage of the roller the pace may be quickened. The pavement shall then be rolled transversely at an angle of forty-five (45) degrees; repeat the rolling in like manner in the opposite direction, then roll parallel with the curb or edging line until the surface is smooth.

Before this last rolling takes place all broken or injured brick must be taken up and replaced with acceptable ones. Portions of the pavement inaccessible to the roller shall be tamped to grade by the use of a hand tamper applied upon a 2-in. plank.

After the final rolling the surface shall be tested with a ten (10) foot straight edge laid parallel with the center line of the pavement and any depressions exceeding one-quarter (¼) of an inch shall be taken out.

All brick laid shall be rolled ready for grouting at the end of the working day.

Cement Grout Filler.—The cement grout used in filling the joints in the brick shall consist of one (1) part of cement and one and one-half (1½) parts of sand.

The cement shall meet the requirements of the Standard Specifications for Portland Cement of the American Society for Testing Materials,

adopted August 16, 1909, with amendments and additions thereto adopted by said Society.

The sand for the cement-sand bed and the grout filler shall be composed of clean, sharp, well graded quartz grains and shall not contain more than 5 per cent of clay or silt. The grains shall be such size that all will pass a No. 12 sieve and that not more than 40 per cent will pass a No. 50 sieve.

As soon as the pavement is rolled and before the filler is applied the pavement shall be thoroughly saturated with water so as to insure the hardening of the cement-sand bed. The brick must be wet when the grouting starts.

The cement and sand for grouting in correct proportions shall be thoroughly mixed dry until the mass assumes a uniform color. From this mixture a small batch not exceeding 2 cu. ft. shall be placed in a suitable box or a machine especially adapted for that purpose. Slowly add water and thoroughly mix until the mixture is of such a consistency that it will readily flow into the joints without separation. Ample time must be taken in preparing this liquid mixture, first making a plastic mortar, then gradually thinning by mixing and slowly adding water; continue the mixing until all is removed and applied to the surface in small quantities. The application should be continued until the joints appear to be filled. Any surplus material remaining on the bricks shall then be swept into the joints. Extreme care must be taken that the joints are not cemented over and that the filler extends down to the bottom of the brick.

After the first coat has had a chance to settle and before the initial set develops, a second coat shall be applied in a similar manner with a somewhat thicker grout. After this application has had time to settle and before the initial set takes place, the pavement shall be finished to a smooth surface with a squeegee having a rubber edge which shall be worked over the brick at an angle with the joints—thus leaving them entirely filled (see Fig. 145).

The contractor shall provide thin metal strips one-sixteenth ($\frac{1}{16}$) in. by six (6) in. by three (3) ft. long and insert same in the brick joints across the street when closing up a stretch of grouting at work intervals, so that the grouting will end in a vertical joint. These strips must be taken out when the grout becomes stiff and before the initial set.

Protection of Filler.—After the surface has been thoroughly inspected and if approved, and sufficient time for setting has taken place so that a coating of sand or earth will not absorb any moisture from the cement mixture, the surface shall be covered with one (1) in. or more of sand or earth to prevent too rapid drying of the filler. This shall be kept moist for at least four (4) days, and no traffic shall be allowed on the street for a period of at least fifteen (15) days.

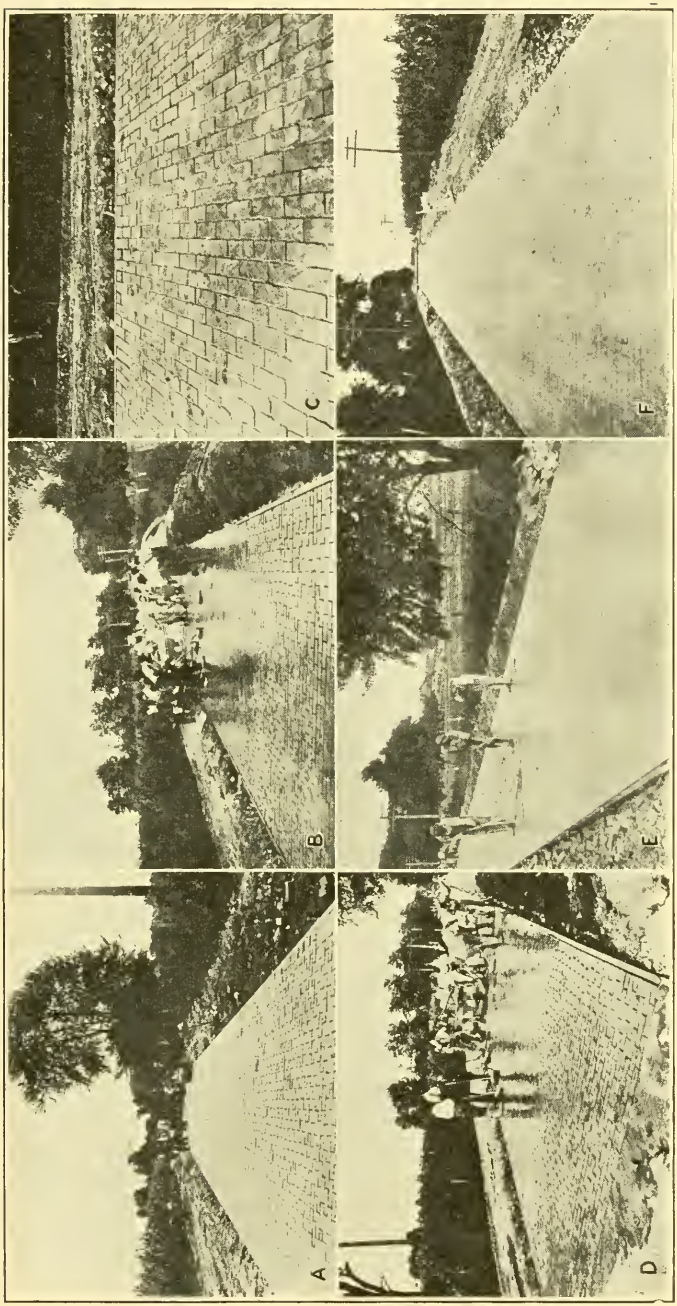


FIG. 145.—Grouting. *A*, Surface ready for grouting. *B*, Applying first grout. *C*, Surface after first grouting. *D*, Applying second grout. *E*, Finishing with squeeges. *F*, Completed surface.

Hillside Brick.—On grades, when ordered by the engineer, standard hillside brick shall be used. These brick shall in quality and test conform to the requirements of these specifications.

The general method of constructing a wire-cut lug hillside pavement shall conform to the standard specifications, except that the bricks shall be laid longitudinally instead of transversely. They shall be grouted in the manner specified for brick pavements except that all the grout in the surface grooves of the wire-cut lug hillside brick shall be broomed out before it shall have time to set up (care being taken not to disturb the grout in the longitudinal joints). This brooming should be done transversely with a rattan broom.

Note.—We strongly advise the use of a small mixer properly equipped for applying the grout. This mixer should be used for the first application, and a suitable box for the second application. When boxes are used the grout shall be removed from same with scoop shovels.

Bituminous Filler.—Where bituminous filler is used the brick must be clean and dry when the filler is applied. It must be heated to the proper temperature between 300 to 380°F. and applied by either conical pouring cans the nose of which rests on the joint and is drawn along the joint or by the squeegee method. The squeegee method is recommended by the Brick people. In this method the hot filler is poured on the pavement and rapidly worked into the joints by hot iron squeegees operated slowly backward and forward at an angle with the joints. The operation is continued until the joints remain full and a thin film of bitumen remains on the surface of the brick. A thin sand or screening coat is spread over the surface and the pavement opened for traffic.

TYPICAL SPECIFICATIONS (NEW YORK STATE, 1922)

Item 47—Concrete Foundation for Pavement

Work. 47.1. Under this item the Contractor shall furnish and place upon a properly prepared subgrade, concrete foundation for pavement and necessary edging of the dimensions shown on the plans or ordered by the Engineer.

47.2. Concrete foundation and edging shall be placed on the subgrade or on the foundation course, and shall not be placed until these are in first class condition true to line and grade in longitudinal and transverse cross-section properly drained and thoroughly rolled and compacted; it being a prime consideration that uniform density in the subgrade or foundation course be secured. Where the subgrade is an old roadbed it must be scarified, reshaped and rerolled for the full width of the pavement.

Wherever the supporting power of the subgrade changes suddenly by reason of change from rock to earth, or of trench excavation which cannot be sufficiently compacted, metal reinforcement shall be furnished and used in the concrete foundation, as shown on the plans or as ordered by the Engineer. Payment for such reinforcement will be made under item of "Metal Reinforcement."

Material. 47.3. Concrete shall consist of a mixture of Portland cement, concrete masonry sand, and broken stone, broken slag or screened gravel. All these materials shall conform in all respects to the requirements given under "Materials of Construction," and all the specifications relating to second-class con-

crete shall apply to work done under this item, in so far as the same do not conflict with the special specifications given below.

Method. 47.4. The concrete shall be mixed in the proportions of one volume of cement to seven and one-half volumes of sand and broken stone, broken slag or screened gravel measured separately. The volumes of sand and broken stone or broken slag or gravel, shall be measured accurately in a manner satisfactory to the Engineer. The relative proportions of fine and coarse aggregate may be varied slightly, as a result of tests for voids by the Engineer, to the end that resulting concrete shall be as dense as possible. The concrete shall in all cases approximate a 1 : 2½ : 5 mix.

47.5. The coarse aggregate shall consist of a well mixed product of clean No. 1, No. 2 and No. 3 stone, slag or screened gravel provided that not more than 25 per cent of the total shall be of No. 1 size.

47.6. The concrete shall be mixed in approved mechanical batch mixers. Mixing shall be continued for at least 1 min. after all the materials are in the mixer drum, at a speed of not less than 10 nor more than 16 r.p.m. and until every particle is coated with mortar and until the batch is of uniform color and consistency. After the materials are once wetted the work shall proceed rapidly until the concrete is in place. The quantity of water used shall be as directed by the Engineer and suitable measuring tanks shall be provided by the Contractor so that the amount of water may be such as to make the separate batches of the same consistency.

47.7. If at any time during the progress of the work the temperature is so low that in the opinion of the Engineer it will within 24 hour drop to 35 °F., the water and aggregates shall be heated and precautions taken to protect the work from freezing for at least 10 days. Should these temperature conditions maintain for two consecutive days, permission must be had from the Division Engineer in writing before proceeding with the work, laying down such requirements of procedure as will be permitted. In no case shall concrete be deposited on a frozen subgrade. All frost lumps must be removed from the aggregates.

47.8. Substantial forms shall be provided and set long the edges of the concrete foundation. They shall be securely staked in position so that they will maintain true line and grade and prevent warping.

47.9. Before any concrete is placed, the subgrade shall be sprinkled sufficiently to dampen it but a muddy condition shall not be allowed. As soon as possible after mixing, the concrete shall be deposited in place and thoroughly spaded or screened so as to bring the mortar flush to the surface. Especial care shall be taken to keep the concrete uniform and to prevent pockets of stone or mortar.

47.10. The surface when completed shall conform to the lines and grades shown upon the plans, and shall be free from depressions and irregularities. No stone shall project above the general surface. All shaping or screening shall be done before the concrete has begun to harden. Any concrete which has not been shaped and finished previous to hardening, shall be removed for the full depth of the roadway and replaced with satisfactory concrete.

47.11. As soon as the concrete has hardened the surface shall be covered with a layer of suitable material as directed by the Engineer.

Edging. 47.12. Concrete edging may be mixed by hand in the manner specified for second-class concrete. In all cases, however, the concrete shall be rammed and spaded so that a dense concrete and a smooth surface will result. Before the concrete has hardened the top shall be finished to a smooth, even surface with trowel or float.

47.13. The forms shall be set and held true to line and grade, and shall not be removed until the concrete has hardened sufficiently, in the judgment of the Engineer. The edging shall be protected from injury until the completion of the contract.

After the removal of the forms, the trenches shall be back-filled with earth and thoroughly tamped.

Measurement and payment.

47.14. The quantity to be paid for under this item shall be the number of cubic yards of concrete foundation and edging for pavement incorporated in the work in accordance with the plans or as directed by the Engineer.

The price bid shall cover the furnishing and placing of all forms and materials, (except Portland cement) all mixing, tamping, finishing and all labor, appliances, and incidental expenses necessary to complete the work. The amount to be estimated shall be computed by multiplying the cross-section of concrete foundation and edging as shown upon the plans or ordered by the Engineer by the total length of concrete foundation and edging measured along the axis of the pavement, making no deductions for catch basins and manholes.

Item 61—Brick Pavement.—Type 1

Item 61A—Brick Pavement.—Type 2

Work.

61.1. Under this item the Contractor shall furnish and place the number of square yards of brick pavement required in accordance with the plans or as ordered by the Engineer. The item will cover the furnishing and placing of all the brick, cushion, grout, expansion joints and all material, labor and other expenses incidental thereto but will not cover the concrete foundation, edging, curbing, manholes, catch basins, etc., which will be paid for under the especially designated items therefor.

Material.

61.2. All bricks or blocks used must be annealed and especially burned for street paving and of the very best quality as regards hardness, dimensions, toughness, straight lines and non-absorption of water.

All brick must be neatly piled outside of the neat lines of pavement and the dumping of brick will not be allowed.

61.3. The paving bricks shall be subjected to abrasion tests conducted by the Commission in the manner and with rattlers of the type adopted February 7, 1911, by the National Paving Brick Manufacturers Association. One sample of bricks shall be taken and tested for every two hundred thousand (200,000) bricks and less than this when conditions warrant. An average loss in weight in a rattler test exceeding twenty-four (24) per centum, or an average absorption of three and one-half ($3\frac{1}{2}$) per centum of water shall cause the rejection of the total quantity that the test represents, provided, however, that if permitted the bricks may be carefully reculled, and new samples taken and tested. If this second test passes the requirements, the bricks represented by it may be used. If this second test fails, no further test shall be permitted but the entire lot shall be rejected. To insure the furnishing of bricks of uniformly acceptable quality, if any "brand" of brick of which three lots, each of ten thousand (10,000) bricks or more, offered consecutively for acceptance tests, fail to meet the requirements for this section without reculling them, then this brand shall be rejected.

All the above tests will be made by the Bureau of Tests of the State Commission of Highways.

61.4. On grades of 5 per cent or over an approved special form of block suitable for steep grades shall be used.

61.5. The size of the brick shall be $3\frac{1}{2}$ in. in width by 4 in. in depth by $8\frac{3}{4}$ in. in length, unless otherwise shown on plans, and shall not vary from the dimensions specified more than $\frac{1}{4}$ in. in width nor more than $\frac{1}{8}$ in. in depth nor more than $\frac{1}{2}$ in. in length. Bricks of a given brand shall not vary among themselves more than $\frac{1}{4}$ in. in depth nor more than $\frac{1}{8}$ in. in width nor more than $\frac{1}{2}$ in. in length in any one shipment. If the edges are rounded the radius shall not be greater than $\frac{3}{16}$ of an inch. One side shall contain lugs of such dimensions that transverse joints will not be less than $\frac{3}{16}$ of an inch nor more than $\frac{1}{4}$ in. in width. Each end shall contain a semi-circular groove of $\frac{1}{8}$-to $\frac{1}{4}$-in. radius, or a bulge of at least $\frac{1}{16}$ in. The grooves shall be horizontal, and shall match perfectly when the bricks are laid in the finished pavement. Bricks in any course shall not vary in width by more than $\frac{1}{8}$ in.

61.6. Not less than 10 days after the concrete foundation has been completed, there shall be laid a bed of clean Cushion Sand as described under "Materials of Construction," which shall be 1 in. thick after being rolled with a roller weighing 150 lb. per foot of width. Before being rolled this bed of sand shall be brought to the proper elevation and crown as shown on the plans by a template of a shape and size satisfactory to the Engineer. After being rolled all irregularities of the surface shall be eliminated and the sand cushion shall be brought to the exact form and section by the use of lutes or hand templates.

61.7. Premoulded longitudinal expansion joints shall be placed alongside each curb or edging, and shall conform strictly to the requirements given under "Materials of Construction."

These joints must extend to the depth of the brick. No transverse joints shall be allowed. The material should be made into strips of suitable length and of the required depth and thickness as shown on plans and should be laid in the pavement with the ends closely joined as the bricks are being laid.

61.8. On the sand cushion prepared as in section 61.6 the bricks shall be carefully set on edge with the best edge up, shall be laid straight and at right angles to the edging line, except at road intersections, where they shall be laid at such angles as directed by the Engineer. All brick shall be laid with the lugs in the same direction, joints shall be close and at right angles to the tops and sides. Each alternate course shall be commenced with a half brick. No half bricks or bats shall be used except at the ends of courses, and no bats shall be less than 3 in. in length and at right angles to the courses. All joints shall be broken with a lap of not less than three (3) inches.

When laying brick on a street or road used in conjunction with a traction company the courses shall be started at the rails and laid toward the curbs or edgings.

All brick shall be clean when placed in the pavement. Brick which in the opinion of the Engineer are not satisfactorily clean, shall be washed before being placed.

In no case shall the sand cushion in front of the pavement be disturbed or walked on during the laying of the bricks.

61.9. After a sufficient number of bricks have been laid, all soft, broken or badly misshapen bricks shall be marked by the inspector and removed by the Contractor. Any bricks slightly spalled or kiln-marked shall be turned over, and should the opposite face be acceptable, it may be replaced in the pavements otherwise, it must be removed.

In laying brick pavement, the inspector shall keep the bricks culled, and the Contractor shall make the necessary changes and replacements so that the work shall at all times be ready for grouting within 300 ft. from the brick-laying.

61.10. After all objectionable bricks have been removed from the pavement and all replacements have been made, the pavement shall be swept clean and thoroughly rolled with a self-propelled tandem roller weighing not over tons and not less than 3 tons. Horse rolling shall not be permitted. This rolling shall start along the outside edges and progress toward the center. It shall then be rerolled diagonally both ways until the surface is even. After final rolling the pavement shall be tested with a 10-ft. straight edge laid parallel with the curb, and any depression exceeding $\frac{1}{4}$ in. shall be corrected and brought to the proper grade. All bricks disturbed in making replacements or correcting depressions shall be settled into place by ramming or by rerolling. All gutter bricks must be brought to grade by ramming.

This rolling shall start along the outside edges and progress toward the center as slowly as possible. After the first passage of the roller, the pace may be quickened. Portions of the pavement inaccessible to roller shall be tamped to grade by the use of hand tamper applied upon a 2-in. board.

If during or after the rolling of the pavement the sand cushion shall work up between the brick more than $\frac{1}{4}$ their depth, the brick shall be taken up and the sand cushion again rolled until firm enough to support the weight of the brick and roller. After final rolling all broken brick must be replaced.

Each section of pavement must be acceptable to the Engineer before the grouting on that section may be commenced.

Grout. 61.11. Grout for filling the joints of brick or block pavements shall be composed of 1 part Portland cement and 1 part grout sand, if hand mixed, and 1 part Portland cement and 2 parts grout sand if machine mixed.

61.12. The box for hand mixing this grout shall be about 4 ft. 8 in. long, 2 ft. 6 in. wide and 1 ft. 2 in. deep, supported on legs of different lengths in order that the mixture shall readily flow to the lowest corner, which shall not be more than 6 in. above the pavement. Any approved mechanical grout mixer may be used.

61.13. If hand mixed, the material, not exceeding 1 sack of cement together with a like amount of sand, shall be placed in the box and mixed dry, until the mass assumes a uniform color. Water shall then be added, forming a liquid mixture of the consistency of thin cream for the first coat and slightly thicker for each succeeding coat. From the time the water is applied until the last drop is removed and floated into the joints of the pavement the mixture must be constantly agitated.

Spreading grout. 61.14. The brick shall be wet to the satisfaction of the Engineer before any grout is placed. The grout shall be removed from the box to the street surface with a scoop shovel and immediately swept into the joints, the mixture in the box being constantly agitated while this is being done.

If a mixer is used, as soon as the grout is deposited upon the surface it must be swept into the joints. The work of grouting shall proceed for the entire width of the pavement, working from the sides toward the center. When sufficient time has elapsed for the grout to thoroughly penetrate all the joints, but before the grout has begun to harden, the section treated shall be gone over a second time in the same manner, care being taken to thoroughly fill all joints to the bottom and flush with the top of the brick. If necessary to secure flush joints, a third, fourth or fifth coat of the grout shall be swept in and smoothed off with a suitable squeegee. The squeegee must in all cases be worked at an angle of 45° with the joints.

Care shall be taken to so conduct the grouting that no part of any joint will receive an application of the second grout until the first is satisfactorily completed, nor of the third until the second is completed, etc. To insure this result metal strips $\frac{1}{16}$ in. by 6 in. by 3 ft. must be inserted, for the full length of the joint, at work intervals; all of the several applications of grout must be completed up to this joint before any grouting is begun on the other side of it.

Covering. 61.15. After the joints are thus filled flush with the top of the bricks and sufficient time for hardening has taken place, the pavement must then be sprinkled, shortly after which 1 in. of suitable material shall be spread evenly over the entire surface, and be kept moist for a period of at least 10 days and until the grout has thoroughly hardened.

During this period the section grouted must remain absolutely free from disturbance or traffic of any kind. Before opening for traffic this cover coat shall be completely removed.

Plastering rail. 61.17. Wherever railway track is encountered in the area to be paved, the rails shall be plastered with a stiff mortar mixed, 1 part of Portland cement to 3 parts of concrete masonry sand. This shall be used to completely fill under the head of the rail on both sides of the web. When this is done no deduction will be made from the paved area for the area of the rails for purposes of payment.

Measurement and payment. 61.18. The quantity of pavement to be paid for under this item shall be the number of square yards placed in accordance with the plans or directions of the Engineer, and shall be computed by multiplying the actual width of pavement, including expansion joints, by the total length of pavement measured along the axis of the road and parallel to the surface, except that the area of manhole covers and catchbasins, where encountered, shall be omitted. The price bid per square

yard shall cover the sand cushion, paving brick, grout, (except Portland Cement), material for expansion joint, sand covering, sprinkling, and all other labor, materials and incidentals necessary to satisfactorily complete the work.

ITEM 61—A

The specifications for this item will be the same as those given under Item 61 and entitled "BRICK PAVEMENT, TYPE 1," except in the following details:

CEMENT-SAND BED.—Not less than 10 days after the concrete foundation has been completed, there shall be spread upon this foundation a bed of cement and concrete masonry sand, consisting of 1 part cement and 4 parts of concrete masonry sand of which the depth shall not be greater than 1 in. after rolling. The sand and cement must be thoroughly mixed dry before placing either by an approved type of mixer, or by hand, on a mixing board or pan. The materials shall be thoroughly mixed until a uniform color is obtained and should be spread on the foundation in this condition. The cement-sand bed shall be struck off with a template and be brought to the exact form and section shown on plans to the required depth below the finished grade. After the bed has been leveled off it shall be rolled with a hand roller weighing about 300 lb. If any depressions develop they shall be filled in and the bed again leveled and the rolling shall be repeated as many times as are necessary to compress the sand bed. Tramping upon the cement-sand bed is prohibited. The inspector must keep the brick culled and the Contractor shall make the necessary changes and replacements so that the work at all times shall be ready for the grouting within 100 ft. of the brick line.

All brick laid must be rolled ready for grouting at the end of the working period and each day's work must be completed in full.

Before the grouting is applied the rolled bricks shall be thoroughly wet by sprinkling. It is important that the bricks be well wet so as to set up the cement-sand bed. An excess of water over that required and taken up by the cement-sand cushion must not be used. The operation of grouting will be followed as for "Type 1."

Payment will be made as for "Type 1" except that it will also cover the cement-sand bed (except PORTLAND CEMENT).

ASPHALT BLOCK PAVEMENT

Asphalt block pavements are an excellent type for extremely heavy Class I traffic particularly where roads of this class pass through villages and the grades are not steeper than about 4 per cent. The pavement shows a smooth uniform surface dustless and practically noiseless. Its life probably lies between 15 and 20 years depending on the quality of block. Failures that occur in shorter time are generally due to inferior block. The quality of block is very important. A mist or light rain makes the pavement very slippery on grades of over 4 per cent. Within a reasonable freight radius of the point of manufacture, this pavement costs

FIG. 146.—Asphalt block on high class residential street. State Highway connecting link through small city.

about the same as brick for original construction. It is used as a surfacing on both concrete and macadam bases. This type of pavement should be used with caution on macadam bases as it is an expensive surface and its form is not as applicable to use on top of macadam as the sheet asphalt type.

The asphalt block pavement laid on New York State Rural Highways has been very satisfactory. The proportion of ingredients is about 70 per cent crushed rock, usually trap, which has passed a ¼-in. ring, about 20 per cent limestone dust to act as filler and approximately 10 per cent of asphaltic cement, molded under a pressure of 2 tons per square inch

of block having a 2-in. depth. This produces a dense asphalt much superior to the ordinary sheet. The asphalt used is Trinidad. This is refined and fluxed so that the resulting A.C. may be varied as to adhesiveness, penetration, etc., to meet varying conditions peculiar to different localities. The penetration is made high enough to give a certain amount of pliancy to the block, to avoid crumbling at the edges and to make the points self-healing.

The use of blocks containing steel anchors, laid across the road, approximately 15 ft. apart, has eliminated any movement of the block under traffic. These blocks are placed at more frequent intervals on curves. Block pavements have been laid using a longitudinal row of these anchor blocks in place of edging. The results appear satisfactory, although under these conditions it is probably desirable to thicken the base at the edge (see Chap. II).

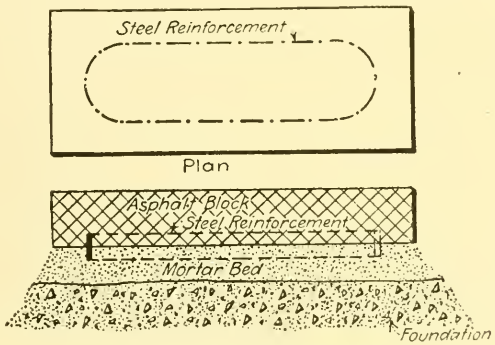


FIG. 147.—Anchor block detail.

After the base is prepared a mixture of 1 to 4 Portland cement mortar is spread ½ in. thick. This mortar bed is carefully screeded and the block laid thereon, joints being broken at least 4 in.

An interesting comparison with brick occurs in the "pinning in" at curbs. Instead of bats being broken by hand, a large mechanical shear is used. Each fractional block is measured and cut to fit exactly.

After being laid, the pavement is given a light coat of sharp sand which is broomed into the joints. Traffic is permitted in 4 or 5 days.

Advantages.—The pavement shows a smooth, uniform surface, dustless and practically noiseless. Its life on Rural Highways has yet to be determined. Pavements that have been down 10 or 15 years are still in good shape. Within a reasonable freight radius from the point of manufacture, it can be laid for approximately the cost of brick.

Disadvantages.—A mist or light rain makes the pavement very slippery. It should not be used on grades over 4 per cent.

Recommended Design.—The following recommended design is for conservative practice in localities having a gross vehicle load limitation of 28,000 lb.

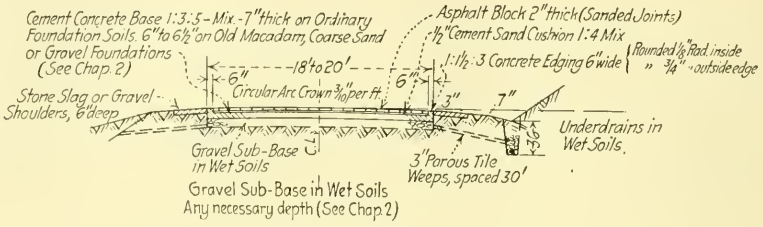

Cement Concrete Base 1:3:5-Mix-7" thick on Ordinary Foundation Soils, 6" to 6½" on Old Macadam, Coarse Sand or Gravel Foundations (See Chap. 2)
Asphalt Block 2" thick (Sanded Joints)
½" Cement Sand Cushion 1:4 Mix
1:1½:3 Concrete Edging 6" wide
Rounded ⅛" Rad. inside
" ¾" " outside edge
18' to 20'
6"
Circular Arc Crown ¾" per ft.
6"
3"
7"
Stone Slag or Gravel Shoulders, 6" deep
Underdrains in Wet Soils.
Gravel Sub-Base in Wet Soils
3" Porous Tile Weeps, spaced 30'
Gravel Sub-Base in Wet Soils
Any necessary depth (See Chap. 2)

FIG. 148.—Recommended design asphalt block.

Suitable Materials.—Materials for concrete base are the same as discussed under asphaltic concretes, page 301.

The block itself being a manufactured product generally laid under a guarantee cannot be too definitely described in a general specification. It is, perhaps, just as well to specify trap rock stone aggregate where this is available as such block apparently wear considerably better than the softer limestone blocks. Well manufactured blocks using stone aggregate with a per cent of wear of 5 or less will probably be satisfactory; the consistency of the bituminous binder had better be left to the manufacturer so long as he understands the traffic and climatic conditions to be met. An example of the ordinary specifications is given below.

Amounts of Material.—Amounts for bases are the same as given under Asphaltic Concrete Pavements.

Design.—The design of base thickness, width and crown is the same as for asphaltic concretes, page 306.

Equipment and General Methods.—Brick paving equipment and methods apply.

Inspection Details.—Inspection is essentially the same as for brick pavement work.

NEW YORK STATE SPECIFICATIONS

ITEM 60—ASPHALT BLOCK PAVEMENT.—APPROVED TRAP ROCK

ITEM 60A—ASPHALT BLOCK PAVEMENT.—APPROVED LIMESTONE

Work. 60.1. Under this item the Contractor shall furnish and place upon a properly prepared foundation asphalt block of the quality specified where shown upon the plans or ordered by the Engineer. This pavement shall be placed upon the old macadam, old concrete pavement, new concrete foundation or on other foundations as ordered by the Engineer and shown upon the plans.

Material. 60.2. The blocks shall be 5 in. in width, by 12 in. in length, by 2 in. in depth, and a variation of more than ¼ in. in length or ⅛ in. in width or depth from these dimensions will be sufficient ground for rejecting any block.

60.3. The blocks shall consist of the following materials:

Asphaltic cement.

Approved crushed trap rock [item 60], or approved crushed limestone [item 60A].

Inorganic dust.

The asphaltic cement shall have the following characteristics:

1. It shall be free from water.

2. The various hydrocarbons composing it shall be present in a homogeneous solution.

3. It shall have a specific gravity at 77°F. of not less than 0.99.

4. It shall have a penetration (77°F., 100 g., 5 sec.) of not less than 15 nor more than 25.

5. It shall have an evaporation loss of less than 2 per cent. The penetration (77°F., 100 g., 5 sec.) of this residue shall be at least 50 per cent of the original penetration.

6. Its solubility at air temperature in carbon disulphide, for the following named products, shall be at least 99.5 per cent for pure bitumen products, 95.0 per cent for Bermudez products, 81.0 per cent for Cuban products and 66.0 per cent for Trinidad products.

7. The solubility of the bitumen, at air temperature, in 76°B. paraffin petroleum naphtha distilling between 140°F. and 190°F. shall be between 65 and 80 per cent.

8. The bitumen shall show between 8 and 18 per cent fixed carbon.

9. It shall show an open flash not less than 375°F.

10. It shall not contain more than 4.7 per cent paraffin scale.

11. It shall show a toughness at 32°F. not less than 10 cm. Toughness is determined by breaking a cylinder of the material $1\frac{3}{4}$ in. in diameter by $1\frac{3}{4}$ in. in height in a Page impact machine (A. S. T. M., 1908). The first drop of the hammer being from a height of 5 cm. and each succeeding blow increased by 5 cm.

12. It shall have a ductility at 77°F., of not less than 8 cm. (Dow mold).

13. All asphaltic cement will be sampled by an Engineer of the Department of Highways and samples sent to the Bureau of Tests, Albany, N. Y.

The crushed rock for coarse aggregate used in the blocks shall be crushed from clean hard rock and shall not contain any soft ingredients. It must be crushed so that every particle will pass a screen of $\frac{1}{4}$-in. mesh.

The inorganic dust, or filler, shall be produced from sound limestone, and shall be powdered to such a fineness that all of it shall pass a 30-mesh sieve and not less than 50 per cent of it shall pass a 200-mesh sieve. Sufficient inorganic dust shall be used to give a minimum percentage of voids in the block, and provide a sufficient medium for absorbing the asphalt cement.

Block composition.

60.4. The block composition shall yield not less than 8, nor more than 11 per cent of bitumen, when extracted with carbon disulphide.

The mineral aggregate of the blocks shall meet the following mesh analyses:

Passing No. 200 sieve at least, per cent	18.0
Passing No. 80 sieve, retained on No. 200 sieve, per cent	12 to 18
Passing No. 40 sieve, retained on No. 80 sieve, per cent	8 to 14
Passing No. 20 sieve, retained on No. 40 sieve, per cent	8 to 16
Passing No. 10 sieve, retained on No. 20 sieve, per cent	15 to 20
Passing $\frac{1}{4}$-in. sieve, per cent	100

The use of dust coated screenings will be cause for rejection. The blocks shall receive a compression in the moulds of not less than 200 tons.

The blocks shall have a specific gravity of not less than 2.45 for trap blocks, [Item 60]; or not less than 2.30 for approved limestone blocks, [Item 60A].

After having been dried for 24 hours at a temperature of 150°F., the blocks shall not absorb more than 0.75 per cent of moisture when immersed in water for 7 days.

The average penetration of a block shall not exceed $\frac{1}{4}$ in. when tested for 1 min. at a temperature of 100°F. with a cylinder $\frac{1}{4}$ in. in diameter loaded with 147 lb.

Method.

60.5. Upon the foundation shall be spread a bed of the thickness shown upon the plans, composed of 1 part Portland cement and 4 parts sand, thoroughly mixed with sufficient water to make a stiff paste.

This mortar bed shall be struck with a template to a true surface, exactly parallel to the top of the proposed pavement surface and 2 in. below it.

The blocks shall be laid while the mortar is fresh and before it has begun to harden. All depressions and other irregularities in the surface shall be corrected by the Contractor immediately.

The blocks shall be laid by the pavers standing upon the blocks already laid and not upon the bed of mortar.

The blocks shall be laid at right angles with the line of the street, and in such a manner that all longitudinal joints shall be broken by a lap of approximately four inches. The blocks shall be so laid as to make the lateral joints as tight as possible, consistent with keeping a good alignment of the courses across the street. When thus laid the blocks shall be immediately covered with clean, fine sand, perfectly dry, and screened through a $\frac{1}{8}$-in. screen. This sand shall be spread over the surface and swept into the joints and be allowed to remain on the pavement not less than 30 days, or until the action of the traffic on the street shall have thoroughly ground the sand into all the joints.

On grades, curves or elsewhere as shown on the plans or as ordered by the Engineer, blocks containing an imbedded anchor of iron or steel of an approved shape shall be furnished. Steel strips, $1\frac{1}{2}$ in. wide, $\frac{1}{8}$ in. thick and from 2 to 4 ft. long may be set on edge between courses as a substitute for anchor blocks. These anchor blocks or steel strips are to be laid in such courses and at such intervals as shown on plans or as directed by the Engineer. Payment for imbedded metal in anchor blocks or for steel strips will be made under the item "Miscellaneous Iron and Steel."

60.6. The materials incorporated into blocks shall be approved by the Engineer, and samples of all materials shall be sent to the Bureau of Tests and they shall pass the tests required by this Bureau for these materials.

60.7. The methods of work and materials used shall at all times be subject to the inspection and supervision of the Engineer on his representative upon the work.

Measurement and payment.

60.8. The quantity to be paid for under this item shall be the number of square yards of asphalt block laid in accordance with the plans or as directed by the Engineer. The price bid shall cover the furnishing and placing of all materials, (except Portland Cement), mortar bed, and all labor and incidental expenses necessary to complete the work. Where placed upon old concrete foundation or upon old macadam the preparation of the foundation to receive the mortar bed will be paid for under item "Cleaning Existing Pavement" or item "Scarifying and Reshaping Old Macadam."

Less Used Pavements.—The text on the following pavements is condensed as they are at present used for comparatively small yardage under special conditions. The specifications give essentials (see page 386).

WOOD BLOCK PAVEMENTS

Wood block can very rarely be used to advantage on rural highways. In exceptional cases, they can be considered. Specifications are given on page 386.

STONE BLOCK PAVEMENTS

Stone block pavements on account of their high first cost and somewhat irregular surface uncomfortable for high speed traffic are generally specified on rural highways only on steep grades Class I traffic roads where the normal pavement adopted is too slippery for safety.

For these conditions they are the best possible and most economic solution considering service and final cost. Specifications are given on page 388. The following recommended design is conservative practice for Class I roads.

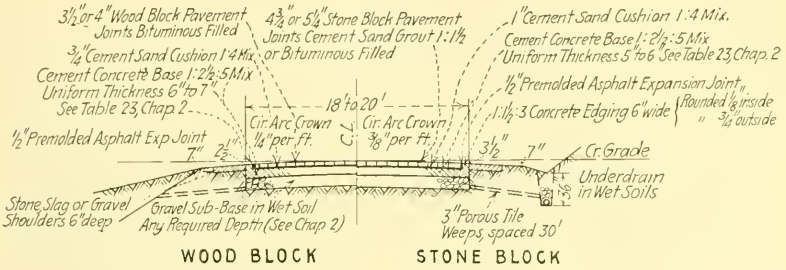


FIG. 149.—Recommended design. Stone and wood block.

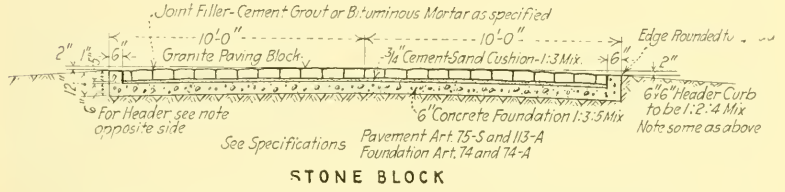


FIG. 150.—Standard section, State of New Jersey (1922).

Small Stone Block Surfacing.—In Germany, Hungary, Austria, and England a surfacing made of granite blocks, ranging in size from 2½ to 4 in., has been used successfully. This pavement is known as "Kleinpflaster" in Germany, and as "Durax" armoring in England. The stone cubes must be cut with considerable accuracy in order to give a smooth and durable surface.

The blocks are laid on a thin sand cushion of about ⅜-in. depth, on either a macadam or concrete foundation; they are thoroughly rammed to give a firm bearing and the joints filled either with clean sand flushed in, or a bituminous filler. The joints do not exceed ¼ in. in width. The course of cubes are laid either diagonally to the direction of the traffic or in concentric rings.

Where the stone is broken by hand the cost is high and it would be impossible to consider its use for rural roads in this country. A machine[1] has, however, been developed in Europe for breaking these cubes which is claimed to produce a satisfactory product at a reasonable rate. It is a belt-driven friction drop-hammer having a stone chisel mounted on the anvil; the hammer head is shaped like a stone-cutter's sledge. The power needed for each machine is about 1½ hp.

[1] A detailed description of this machine is given in *Engineering News*, March 27 1912.

About 400 of these machines are in operation, and a plant in Sweden is turning out 700,000 sq. yd. of pavement per year with 62 machines.

Provided the stone cube surface exclusive of base can be laid for $2 to $3 per square yard, it seems a type that must be seriously considered on steep grades Class I traffic particularly for resurfacing old pavements under reconstruction programs. A price as low as this, however, would probably necessitate the use of convict labor in the manufacture of the cubes.

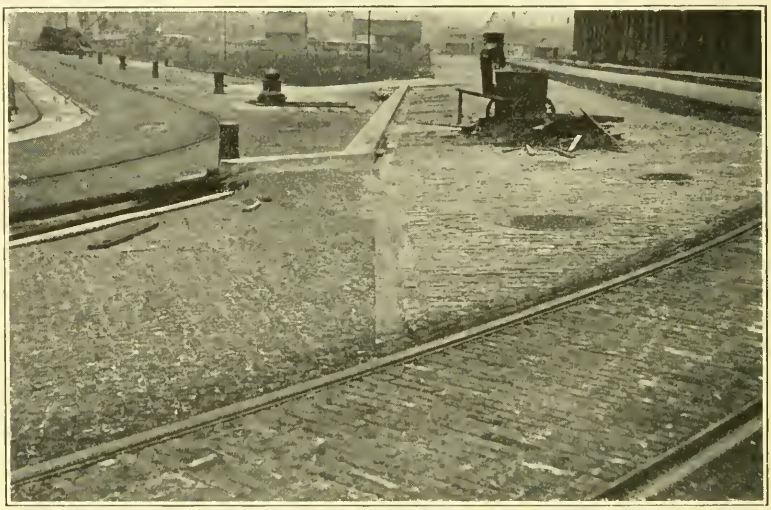


FIG. 151.—Small granite cube pavement, Brooklyn Navy Yard.

McCLINTOCK CUBE PAVEMENTS

This is a patented pavement devised by J. Y. McClintock, County Engineer of Monroe County, N. Y. The patent has run out and it is available for use without the drawbacks of patent limitations. It is very similar to "Kleinpflaster" except that under his patent artificial cubes as well as stone cubes are proposed. It appears to be a very promising type.

The construction is essentially as shown in Fig. 153 and consists of a top course of 2¼-in. cubes placed on a thin sand, cement sand or bituminous cushion supported by either a macadam or concrete base. The cubes have been made of concrete, vitrified paving brick material and stone as in Continental practice.

They are loaded, hauled and dumped like broken stone; laid in close contact by means of a pallet and rake 128 at a time on a sand cushion ¼ to ½ in. thick, no care being taken to break joints. They are then

rolled to bring to an even and firm bearing; the joints are filled with a sandy loam and the surface treated with a light coat of light road oil or cold tar if the foundation is macadam. The joints are grouted if the foundation is concrete. Temporary shoulders of 2-in. plank are put down

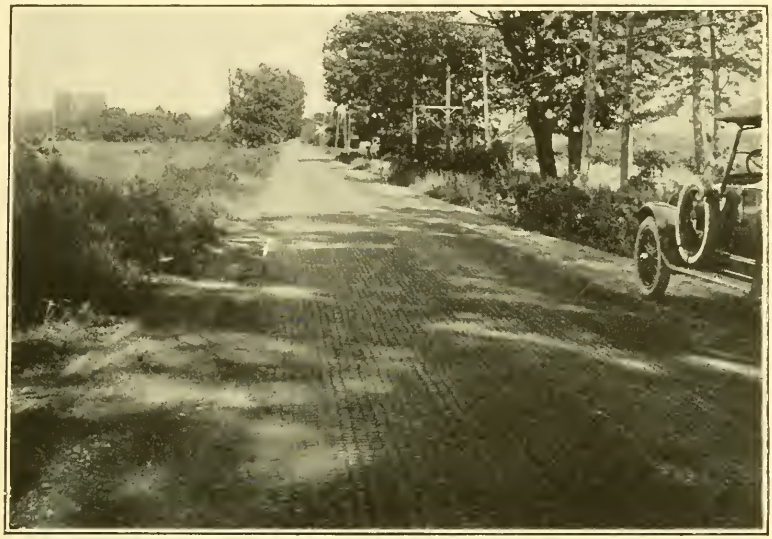


FIG. 152.—Brick cubes on gravel base. Eight years old.

during the laying of the cubes after which they are removed and replaced with broken stone or gravel as shown in Fig. 153.

The experience of the past thirteen years has shown that this form of construction using a sand-tarred joint is flexible under frost action which makes it suitable as a surfacing on a macadam base. It keeps its shape

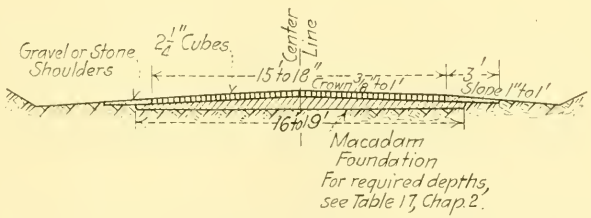


FIG. 153.—Typical section cube pavement on macadam base.

under traffic and shows no tendency to ravel or break down at the edges and can be successfully held with a macadam or gravel shoulder without the formation of a rut along the edge which is a difficulty always encountered where a rigid edging is designed. It gives a satisfactory surface in both wet and dry weather and can be laid late in the season. The cube require comparatively little inspection and can be successfully used as a

patch in maintenance with simple manipulations. They reduce the tonnage and freight cost where imported materials are required. The cubical form simplifies laying and makes a well-balanced block to resist rupture. This type is essentially the macadam type with a perfect shaped macadam unit, the cube. Concrete cubes have not served satisfactorily, failing in spots, but this is to be expected as it is not a reliable material for a road surfacing of this nature (that is for such small units). Vitrified shale cubes with wide sand joints laid on a macadam base have shown ability to stand medium traffic. Vitrified shale cubes

FIG. 154.—Laying brick cubes by means of pallet (128 cubes at a time).

with close tarred joints laid on a thick macadam base serve very satisfactorily under moderately heavy traffic, and these cubes laid on a concrete foundation and grouted meet all but the heaviest traffic satisfactorily.

Consider briefly the present tendencies in highway construction. There are two distinct types: The flexible form represented by the macadams and the rigid types, such as brick, asphalt, stone block, etc., having concrete foundations. Each has a distinct field and their relative economy depends largely on the traffic.

It is sufficient for this discussion to note that macadams are suitable for light and medium traffic (Classes II and III); that they are able to withstand climatic changes better than the rigid pavements and that with a moderate yearly expenditure they can be kept in good condition when used under the volume of traffic stipulated.

They fail either under high velocity traffic or heavy hauling; the first being a surface failure and the second a foundation failure for most of the roads in this locality but a surface failure for some which have a thick

well-consolidated base. That is, if some better flexible surface can be used on a first-class macadam foundation, this type of road will be able to handle a heavier volume of traffic than at present with a moderate maintenance charge. The indications are that the brick cubes with sand-oiled joints will serve this purpose.

The rigid roads develop defects due to temperature changes; frost heave and the settlement of fills. Subsequent movement is localized along these lines and eventually expensive repair and reconstruction is

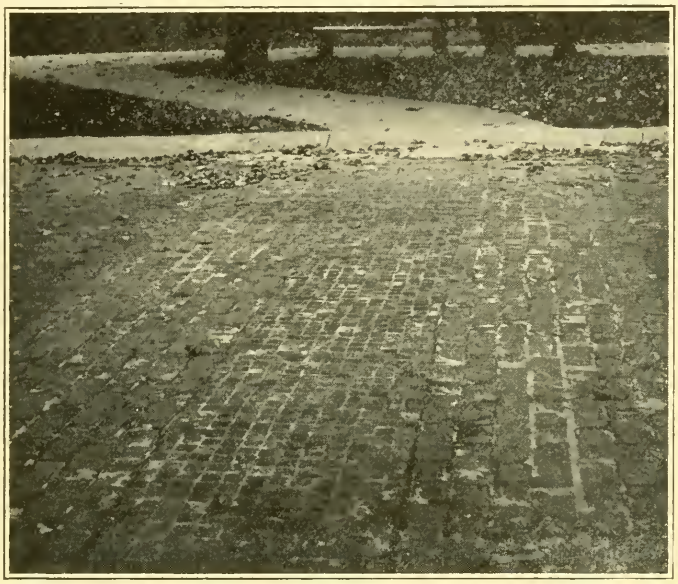


FIG. 155.—Grouted brick cubes 10 years old. In better shape than adjacent large brick block.

necessary. Under heavy traffic, however, the cost is less than for the macadam type and the inconvenience of continual repairs is avoided.

The first cost of standard rigid pavements is so high that designers often hesitate to use them where they are actually needed. If it were possible to reduce the cost and yet obtain practically the same class of improvement a larger mileage could be used to advantage.

The indications are that the brick cubes on a concrete foundation will serve this purpose at a cost considerably less than the present paving brick.

Highway designers do not hesitate to use macadam for the light traffic roads or expensive rigid constructions for the extremely heavy traffic; the great mileage that lies on the verge of either form of construction offers the real difficulty. It is for this class of road that the cubes are particularly adapted by reducing the cost of brick and increasing the

efficiency of macadam. This applies also to the resurfacing of concrete and macadam roads which on steep grades is an annoying problem to the highway engineer.

The author believes that provided this type fulfills its present indications that it will meet a recognized need in highway construction particularly in reconstructive programs and for this reason has given more space than perhaps is justified to a method which has not been tested out by a large mileage of construction.

This type of surface compares favorably in initial cost with asphaltic concretes. It is adaptable to manufacture by convict labor.

Item 59—Wood Block Pavement
(New York State 1922)

Work. 59.1. Under this item the Contractor shall furnish and place upon a properly prepared foundation wood block of the quality specified where shown upon the plans or ordered by the Engineer.

This pavement shall be placed upon the old macadam, old concrete pavement, new concrete foundation or on other foundation as shown on the plans and ordered by the Engineer.

Material. 59.2. The blocks shall be from 6 to 9 in. long and shall average 8 in.; they shall be 3 in. in depth and from 3 to 4 in. in width; but all blocks in one piece of pavement shall be of uniform width. No variation greater than $\frac{1}{16}$ in. shall be allowed in the depth and $\frac{1}{8}$ in. in the width of the blocks.

59.3. Blocks shall be made from Southern yellow pine, North Carolina pine, Norway pine, black gum or tamarack; only one kind of wood however shall be used in one piece of pavement.

Yellow pine block shall be made from what is known as Southern yellow pine, well manufactured, full size, saw butted, all square edges, and shall be free from the following defects:

Unsound, loose and hollow knots, worm holes and knot holes, through shakes and round shakes that show on the surface. In yellow pine timber the annular rings shall average not less than six to the inch and shall be in no case less than four to the inch, measured radially.

Norway pine, gum, North Carolina pine and tamarack block shall be cut from timber that is first-class in every respect, and shall be of the same grade as that defined for the Southern yellow pine.

59.4. The creosote oil with which the blocks shall be treated shall conform to either of the following specifications, designated as "A" and "B."

The preservative to be used under this specification shall be a product of coal gas, water gas or coke oven tar, which shall be free from adulterations and contain no raw or unfiltered tars, petroleum compounds, or tar products obtained from processes other than those stated.

Specification "A"

The specific gravity shall not be less than one and eight-hundredths (1.08) nor more than one and fourteen hundredths (1.14) at a temperature of thirty-eight (38) degrees centigrade.

Not more than three and one-half ($3\frac{1}{2}$) per centum shall be insoluble by continuous hot extraction with benzol and chloroform.

On distillation, which shall be made exactly as described in Bulletin 65 of the Railway Engineering and Maintenance of Way Association, the distillate, based on water free oil, shall not exceed one-half ($\frac{1}{2}$) of one (1) per centum at one

hundred and fifty (150) degrees centigrade, and shall be not less than thirty (30) nor more than forty (40) per centum at three hundred and fifteen (315) degrees centigrade.

The oil shall contain not more than three (3) per centum of water.

SPECIFICATION "B"

It shall be completely liquid at thirty-eight (38) degrees centigrade, and shall have a specific gravity at that temperature of not less than one and three hundredths (1.03) nor more than one and eight hundredths (1.08).

It shall contain not more than two (2) per centum of matter insoluble by hot extraction with benzol and chloroform.

On distillation, which shall be made exactly as described in Bulletin No. 65 of the American Railway Engineering and Maintenance of Way Association, the distillate based on water free oil shall be within the following limits:

At 210°C., not more than 5 per cent.

At 235°C., not more than 35 per cent.

At 315°C., not more than 85 per cent.

The oil shall yield a coke residue not exceeding three (3) per cent.

The distillate, between 210°C. and 235°C., shall yield solids on cooling to 15°C. The preservative shall contain not more than 3 per cent of water.

Sampling of oil.

59.5. The manufacturer of the oil shall permit full and complete inspection and sampling at the factory at which the oil is produced, of all materials either crude or refined, entering into the manufacture of the finished product itself, in order that the materials used can be determined to be in accordance with the foregoing requirements. He shall also submit satisfactory proof of the origin of all materials entering into the composition of the finished product.

Samples of the preservative taken by the inspector from the treating tank during the progress of the work shall at no time show an accumulation of more than 2 per cent of foreign matter, such as sawdust or dirt.

59.6. The blocks shall be treated with the preservative above described, so that they shall contain at least 16 lb. of the same per cubic foot of timber.

The manufacturer of the block shall equip his plant with all necessary gauges, appliances and facilities to enable the inspector to satisfy himself that the requirements of the specifications are fulfilled.

Method.

59.7. Upon the foundation shall be spread a bed of cement mortar at no place less than ½ in. in thickness, composed of one part Portland cement and four parts sand thoroughly mixed dry. This mortar bed shall be struck with a template to a true surface exactly parallel to the top of the proposed pavement surface and 3 in. below it. The bed shall be sprinkled, immediately in advance of the block laying, with clean water by hand sprinklers.

59.8. On the mortar surface prepared as described, the blocks shall be laid with grain vertical and at such angles with the curb as the Engineer may direct. The block shall be laid in straight and parallel courses and set loosely together but the joints shall not exceed ⅛ in. and the blocks shall not be driven together. Each course of blocks shall be of uniform width and depth, with end joints broken by a lap of not less than 2½ in. Only whole blocks shall be used except in starting courses, cutting closures, or where specially permitted by the Engineer. Expansion joints of the same character as is specified for "Brick Pavements" shall be used as shown on the plans or as ordered by the Engineer. On steep grades or elsewhere as shown on the plans or as ordered by the Engineer, iron or steel plates shall be furnished, inserted and secured in the transverse joints. Such plates shall conform exactly to the surface of the paving. Payment for them will be made under item "MISCELLANEOUS IRON AND STEEL."

Closures shall be carefully cut and trimmed by experienced men, the portion of the blocks used shall be free from defects and the cut end shall hava a surface perpendicular to the top of the block and cut at a proper angle to give a close joint. In laying block the pavers must stand on the block previously laid.

After the laying is completed, defective blocks shall be carefully culled out, low blocks raised, the courses carefully aligned and the blocks spaced up. The pavement shall then be rolled by a self-propelled tandem roller weighing not less than 2½ tons nor more than 5 tons; the pavement being at the same time lightly sprinkled and the rolling continued until a uniform surface is obtained. Upon the completion of the rolling any defective blocks shall be removed and be replaced with sound blocks, and displaced blocks shall be realigned. The joints in the pavement shall then be immediately filled in the manner hereinafter described. If deemed advisable by the Engineer, portions of pavement laid with blocks which have become "dried out" shall be sprinkled with water at frequent intervals before joints of same are filled.

59.9. After rolling, the blocks shall be flushed with an approved bituminous filler heated to at least 300°F., which shall be poured over the whole surface and well forced into the joints by rubber squeegees. While the bituminous filler is still hot it shall be immediately followed with a thin coating of clean dry sand. Before turning traffic onto the pavement a coating of ½ in. in thickness of dry screened sand shall be spread over the entire surface.

Measurement and payment.

59.10. The quantity to be paid for under this item shall be the number of square yards, including expansion joints, of pavement laid in accordance with the plans and as directed by the Engineer.

The price bid shall cover the furnishing and placing of the mortar bed, (except PORTLAND CEMENT), wood block, bituminous filler and sand surfacing and all other labor and incidental expenses necessary to complete the work.

ITEM 62—STONE BLOCK PAVEMENT.—TYPE 1
ITEM 62A—STONE BLOCK PAVEMENT.—TYPE 2

Work.

62.1. Under this item the Contractor shall furnish and place upon a properly prepared foundation Stone Block pavement of the quality specified below, as shown upon the plans or directed by the Engineer.

The item will include the furnishing and placing of all the block, sand cushion, grout, expansion joints and all material, labor and other expenses incidental thereto, but will not include the concrete foundation, edging, curbing, manholes, catch basins, etc., which will be paid for under the especially designated items therefor.

Material.

62.2. The dimensions of granite or other blocks except of Medina sandstone shall be as follows: Not less than 8 in. nor more than 12 in. long on top, not less than 3½ in. nor more than 4½ in. wide on top, and not less than 4¾ in. nor more than 5½ in. deep. They shall be dressed so that after laying no measurement of any joint shall show a width of more than ½ in. for a depth of 1 in., or a width of more than 1 in. in any part of the joint. The head of the block shall be so cut that it shall not have a depression in it more than ⅜-in. deep, and the edges and corners must be full unchipped and unbroken. All blocks shall be sorted and laid in straight courses of uniform width and depth.

The dimensions of the Medina sandstone blocks shall be as follows: Not less than 8 in. nor more than 13 in. long on top; not less than 3 in. nor more than 5½ in. wide on top and not less than 6 in. nor more than 7 in. deep. They shall be dressed so that after laying no measurement of any joint shall show a width of more than ½ in. for a depth of 2½ in. or a width of more than 1 in. in any part of the joint. The head of the block shall be so cut that it shall not have a depression in it more than ⅜ in. deep and the edges and corners must be full unchipped and unbroken. All blocks shall be sorted and laid in straight courses of uniform width and depth.

62.3. The blocks shall be of stone of medium sized grain showing an even distribution of constituent material. They shall be of uniform quality and texture, without seams, scales or disintegration. They shall be made from rock which when tested in the Deval Rattler will show a "coefficient of wear" of more than 7 and less than 14. All blocks for any one contract shall be from the same quarry unless otherwise directed.

Method. 62.4. On the prepared foundation, sufficient clean Cushion Sand as described under "Materials of Construction" shall be spread to such a thickness that after the pavement has been thoroughly rammed or settled the sand under the block shall be nowhere less than 1 in. thick.

Premoulded longitudinal expansion joints shall be placed along side each curb or edging and shall conform strictly to the requirements given under "Materials of Construction."

These joints must extend to the depth of the block. No transverse joints shall be allowed. The material should be made into strips of suitable length and of the required depth and thickness as shown on plans and should be laid in the pavement with the ends closely joined as the block are being laid.

On the sand cushion above specified the blocks shall be set vertically on edge in close contact with each other, and in straight rows across the road at right angles to the curb, except at intersections or curves, where the angle of the rows with the curb shall be varied to meet the conditions. Blocks in adjoining rows shall be set to break joints not less than 3 in. All blocks shall be set so that when thoroughly rolled or settled to a firm, unyielding bearing, they will then be true to lines, grades and cross-sections, and have no joints greater than the maximum allowable. All depressions or irregularities in the surface shall be corrected to the satisfaction of the Engineer. Only practiced and competent pavers shall be employed in laying the blocks.

After the blocks are laid, sufficient approved clean gravel shall be spread over the surface and swept into the joints so as to fill the later to a depth of about 2 in. from the bottom. The blocks shall then be thoroughly rolled until firm, with a roller weighing not less than 6 tons, even and true to the lines, grades and cross-sections. Blocks not brought to true surface by rolling shall be rammed.

Portland cement grout mixed in proportions of 1 part cement and 2 parts sand shall then be poured into the joints until the grout flushes to the surface of the pavement. The grout shall be broomed when required, and the pouring and brooming shall be continued until all the joints are thoroughly filled, and the grout is even with the highest part of any and all blocks. Before grouting the blocks shall be wet by sprinkling or otherwise. Grout shall be mixed as specified under Item 61.

Covering. 62.5. After grouting shall have been completed and the grout shall have sufficiently hardened, a coating of suitable material about 1 in. deep shall be spread over the whole surface of the grouted pavement, and the road shall then be sprinkled with water. This covering shall be kept wet, and no travel of any kind shall be allowed on the completed pavement for at least 10 days thereafter, nor until the grout shall have thoroughly set, when the covering shall be completely removed.

Measurement and payment. 62.6. The quantity to be paid for under this item shall be the number of square yards of pavement within the edging or curbing laid in accordance with the plans and as directed by the Engineer.

The price bid shall cover the furnishing and placing of all materials, (except Portland Cement), the spreading of sand cushion, the laying, rolling, grouting, surfacing and all labor and incidental expenses necessary to complete the work.

Item 62—A

The specifications for this item will be the same as those given under Item 62 and entitled "Stone Block Pavement, Type 1," except in the following details:

Cement-Sand Bed.—Not less than 10 days after the concrete foundation has been completed, there shall be spread upon this foundation a bed of cement and concrete masonry sand, consisting of 1 part cement and 4 parts of concrete masonry sand of which the depth shall not be greater than 1 in. after rolling. The sand and cement must be thoroughly mixed dry before placing either by an approved type of mixer, or by hand, on a mixing board or pan. The materials shall be thoroughly mixed until a uniform color is obtained and should be spread on the foundation in this condition. The cement-sand bed shall be struck

off with a template and be brought to the exact form and section shown on plans to the required depth below the finished grade. After the bed has been leveled off it shall be rolled with a hand roller weighing about 300 lb. If any depressions develop they shall be filled in and the bed again leveled and the rolling shall be repeated as many times as are necessary to compress the sand bed. Tramping upon the cement-sand bed is prohibited. The inspector must keep the block culled and the Contractor shall make the necessary changes and replacements so that the work at all times shall be ready for the grouting within 100 ft. of the block line.

All block laid must be rolled ready for grouting at the end of the working period and each day's work must be completed in full.

Before the grouting is applied the rolled block shall be thoroughly wet by sprinkling. It is important that the blocks be well wet so as to set up the cement-sand bed. An excess of water over that required and taken up by the cement-sand cushion must not be used. The operation of grouting will be followed as for "Type 1."

Payment will be made as for "Type 1" except that it will also cover the cement-sand bed (except PORTLAND CEMENT).

CHAPTER IV

MAINTENANCE AND RECONSTRUCTION

Maintenance is more a matter of business organization than it is of technical engineering knowledge. Reconstruction is primarily an engineering proposition. Effective maintenance methods and the reasonable uses of different materials for repair have been quite well determined by practice. Existing flaws in maintenance practice are due largely to insufficient funds and political interference with the personnel of the maintenance organization. Of these two difficulties, lack of funds is the most serious. Funds are a legislative tax problem and a proper solution always lags behind the necessities of the situation. For years, engineers have warned legislative bodies that more adequate provision must be made for repair but active steps to provide such funds have been slow in developing. This is natural as it is difficult for a non-technical man to appreciate the necessity before he has some physical evidence to support the statement and such evidence is only furnished by roads which have gone to pieces. Modern conveniences cost money and no expedient has yet been devised to avoid "paying the piper." At the present time, the necessity for more adequate sums is receiving popular attention and support in states having improved systems of an average age of 10 years or more and there is every indication that remedial action will be taken. Improved highways have demonstrated their worth so thoroughly that there is no danger of any community permitting them to continue permanently in poor condition. Reasonable legislative action depends on engineering estimates of maintenance and renewal costs.

Maintenance and Renewal Costs.—There are two general classes of estimate.

(*a*) For drafting a general legislative tax program.

(*b*) Yearly budget estimates.

The first type of estimate requires consideration of future conditions. The second class states definitely the immediate requirements of the situation. The first class of estimate is subject to considerable uncertainty on account of fluctuating labor and material costs, change in traffic volume, spasmodic maintenance, control of truck loading and speed, etc. but a reasonably close approximation can be derived by an experienced maintenance man. The yearly budget estimates are an easy definite proposition as they are based on actual physical evidence.

TABLE 30.—PROBABLE AVERAGE MAINTENANCE AND RENEWAL COSTS FOR DISTRICTS SIMILAR TO WESTERN NEW YORK
(COMPILED IN 1922)

Computed for normal conditions. Exceptionally favorable conditions in regard to maintenance appropriations and personnel of the force might easily reduce maintenance and renewal costs 20 to 30 per cent (see Table 37)

Type of pavement	Width, feet	Average depth, inches	Construction costs		Yearly maintenance		Renewal[3]		Total maintenance and renewal		Total interest on construction, maintenance and renewal	
			Contract cost per square yard pavement only	5 per cent interest on cost	Pavement only per square yard	Shoulders, pitches, guard rail, etc.	Assumed normal life	Yearly cost for renewal	Per square yard	Per mile	Per square yard	Per mile
Column No. 1	2	3	4	5	6	7	8	9	10	11	12	13
Class I Traffic (2,000 or more Vehicles Daily 10-hour Count in Summer)												
Stone block on concrete base	18–20	12	$5.50	$0.275	$0.005	$0.020	30–35	$0.100	$0.125	$1,400	$0.400	$4,400
Brick on concrete base	18–20	11	4.20	0.210	0.015	0.020	15–20	0.160	0.195	2,150	0.405	4,450
Asphaltic concrete on cement base	18–20	10	3.50	0.175	0.020	0.020	10–15	0.170	0.210	2,300	0.390	4,300
Reinforced cement concrete[1]	18–20	8	3.20	0.160	0.015	0.020	12–15	0.160	0.195	2,150	0.360	4,000
Penetration bituminous macadam[1]	18–20	13	2.50	0.125	0.070	0.020	5– 9	0.200	0.290	3,200	0.420	4,600
Class II Traffic (800–2,000 Vehicles Daily 10-hour Count in Summer)												
Reinforced cement concrete[1]	16–18	8	$3.20	$0.160	$0.010	$0.015	15	$0.145	$0.170	$1,700	$0.330	$3,300
Asphaltic concrete on macadam base	16–18	12	3.00	0.150	0.020	0.015	12	0.150	0.185	1,850	0.335	3,350
Brick cubes on macadam base	16–18	12	3.00	0.155	0.020	0.015	12	0.160	0.195	1,950	0.345	3,450
Penetration bituminous macadam	16–18	12	2.20	0.110	0.040	0.015	10	0.120	0.175	1,750	0.285	2,850
Waterbound macadam (oiled)	16–18	12	1.90	0.095	0.080	0.015	8	0.110	0.205	2,050	0.300	3,000
Class III Traffic (300 to 800 Vehicles Daily 10-hour Count in Summer)												
Penetration bituminous macadam	12–16	10	$1.90	$0.095	$0.030	$0.012	12	$0.100	$0.140	$1,100	$0.240	$1,900
Waterbound macadam	12–16	10	1.60	0.080	0.060	0.012	10	0.070	0.140	1,100	0.220	1,800
Class IV Traffic (Less than 300 Vehicles Daily)												
Waterbound macadam	8–12	9	$1.50	$0.075	$0.040	$0.012	12	$0.060	$0.110	$ 650	$0.180	$1,100
Gravel[2]	8–12	10	1.00	0.050	0.040	0.012	8	0.030	0.080	500	0.130	800

[1] These types eventually resurfaced with asphaltic concrete or some form of standard block or cube surface.
[2] This type can be temporarily used under heavy traffic but for a volume of over 400 to 500 daily it generally develops disagreeable waves known as rythmic corrugations.
[3] Based on maximum allowable roughness of 250 inches per mile Vialog measure without exceeding normal maintenance expenditures.

Legislative Tax Estimates.—Reliable estimates of the future cost of maintenance and renewal depend more on personal knowledge and personal records of an experienced engineer than they do on the exact application of official published reports of maintenance costs. Students may well bear in mind that the usual official report on maintenance expenditure is a broad average, subject to misinterpretation due to inaccuracies of bookkeeping, inadequate strength of some of the pavements, spasmodic appropriations for maintenance, difference in age of pavements, difference in volume of traffic, etc. If due allowance is made for these factors, the values finally adopted often depart considerably from published figures.

Table 30, page 392, gives a basis for future cost estimates which can be used with assurance of reasonable accuracy for conditions similar to New York State. This is a conservative estimate assuming average conditions of efficiency. If the roads are designed of adequate strength and are maintained under an unusually effective system of appropriation and personnel, the maintenance and renewal costs could probably be reduced about 20 to 30 per cent, see Table 37, page 416. The data was derived as follows:

In order to avoid as much as possible needless inaccuracies, this discussion is based on careful analysis of the records of Division 7, N. Y. State Department of Highways of which the author has personal knowledge, supplemented by general State Reports of New York and Massachusetts. The data is analyzed in two ways. First: Reported average costs are modified for average conditions of age, strength, volume of traffic and effectiveness of maintenance. This gives a good basis for future estimates under prevailing conditions. Second: Typical individual roads are selected which we know are adequate in strength and have received moderately good attention; the costs for these special roads are tabulated. This method indicates what can be done under good supervision with adequate funds. Division 7 is selected for analysis as it has been used throughout this series to illustrate the practical application of theories of finance, type selection, traffic volume, etc.

Yearly Costs Per Vehicle Mile.—The costs given in Table 30 expressed in terms of vehicle miles may be roughly approximated as follows:

TABLE 30A

Class of traffic	Assumed average daily volume	Average cost of maintenance and renewal per vehicle mile	Average cost of interest maintenance and renewal per vehicle mile
Class I	4,000	$0.002	$0.003
Class II	1,500	0.003	0.006
Class III	600	0.005	0.008
Class IV	200	0.007	0.014

The saving in traffic operation cost due to well maintained hard surfaced roads is probably about $0.01 per ton mile which indicates that modern improved roads can probably be justified by economic travel return for volumes of traffic of over 300 daily but that for traffic of less than this amount other more indirect benefits must be considered to justify hard surfaced year round pavements. (See also Fig. 6, page 24, Chap. I.)

Basis Conditions Division No. 7, N. Y. State Dept. of Highways.—This Division includes six counties in Western N. Y. having an area of 3,600 square miles an assessed valuation 1920 of approximately $523,000,000, a total motor vehicle registration 1920 of 58,000, a total road mileage of 6,700 miles. At present there are 870 miles of State Improved Roads under maintenance and the following analysis is based on official cost reports for this mileage, modified by personal knowledge of conditions. The executive personnel of this division has been excellent; it is as free from objectionable political interference as any locality is likely to be. There is no great frequency of overloaded truck traffic. The main difficulty has been lack of adequate funds. Table 31 shows at a glance that due to lack of funds and average age, the maintenance costs as reported must be modified if used as a basis for long time legislative programs. Table 30 shows the necessary modified values.

Independent Check on Essential Correctness of Table 30 for Legislative Estimate Purposes.—Table 30 was built up from a detailed study of yearly maintenance figures and records of pavement durability. In order to check these results, the following test was made, approaching the problem from an entirely different angle based on independent data. The essential agreement of the two methods indicates that the data given in Table 30 is a safe base for territory similar to Western New York. The following tabulation and foot note are self explanatory.

Division 7 New York State Highways

(Average Traffic Conditions Class II)

Tabular Comparison of Reasonable Estimated Requirements for Maintenance and Renewal Based on Table 30 (Class II Traffic) as Compared with Actual Appropriation Expenditures

Year	Miles of road under maintenance	Table 30 normal requirements per mile per year	Estimated normal yearly requirements Table 30	Actual appropriations maintenance and renewal
1914[1]	510	$1,100	$ 600,000	$ 360,000
1915[1]	590	1,200	700,000	376,000
1916[1]	660	1,300	900,000	330,000
1917	690	1,600	1,100,000	606,000
1918	720	1,700	1,200,000	1,071,000
1919[2]	750	1,800	1,400,000	674,000
1920	780	1,900	1,500,000	874,000
1921	840	1,800	1,500,000	1,080,000
1922	860	1,800	1,600,000	1,200,000
Totals...	...	.....	$10,500,000	$6,571,000

[1] Table 30 modified for prewar price scale.

[2] Emergency war appropriation (army truck damage).

This table indicates that in 8 years actual appropriations have lagged behind reasonable upkeep requirements $4,000,000.

Table 31, page 396, shows that in Jan., 1923, the reconstruction program for worn out surface is 7 years behind normal renewal for waterbound and 4 years behind normal renewal for bituminous macadams and that to bring the system up to reasonable standard 300 miles should be immediately resurfaced. Such work will cost approximately $14,000 to $22,000 per mile or a total of approximately $5,000,000 which checks the deficit in appropriations obtained by the application of Table 30 to this district.

The data is analyzed, pages 398 to 415, for effect of strength, age and traffic volume. The use of Table 30 in connection with legislative tax estimate, Division 7, is illustrated for the benefit of the student on page 49, Chap. I.

TABLE 31.—BASIC CONDITIONS DIVISION 7, JAN., 1923—MAINTENANCE COSTS (RENEWAL COST NOT CONSIDERED)

Compiled by W. G. Harger for illustrative purposes

Type of pavement	Total mileage (1)	Physical modifying conditions						Effect physical conditions shown in Columns 2 to 7 should have on necessary costs (8)	Approximate average cost maintenance pavement per year (5 year average) (9)		Remarks	
		Average traffic conditions (2)	Actual pavement strength (3)	Actual average age, years (4)	Estimated reasonable average age for completed system provided renewals were properly made (5)	Per cent mileage needing resurfacing at present (6)	Normal yearly per cent resurfacing long term basis (7)		Per mile	Per square yard	Adequacy of actual expenditures (10)	Finally adopted actual relation of reported maintenance costs to normal long time condition, considering existing appropriation limitations as well as physical conditions prevailing
Gravel	5	Class III −	Adequate	6.1	5 years Class III (minus)	44	10	High	$500	$0.065	Low	Normal
Waterbound macadam[1]	370	Class II −	Low	8.3	5 years Class II (minus)	70	10	High	580	0.065	Low	Normal (minus)
Penetration bituminous macadam	244	Class II	Moderate	8.0	6 years Class II	35	8	High	400	0.043	Slightly low	Normal (plus)
Asphaltic concretes (macadam base)	25	Class II +	Moderate	5.0	6 years Class II	5	8	Normal (minus)	120	0.012	Adequate	Normal (minus)
Asphaltic concretes (concrete base)[2]	36	Class I −	Adequate	6.6	7 years Class I	20	7	Normal (plus)	160	0.017	Adequate	Normal
Cement concrete (1:2:4 mix or better)	124	Class II +	Moderate	2.4	7 ycare Class II (plus)	1	7	Very low	40	0.004	Adequate	Very low
Cement concrete (1:2½:5 mix)	20	Class II	Moderate	5.0	3 years Class II	100	16	High	450	0.048	Low	Normal
Brick (concrete base)	25	Class I	Adequate	7.5	9 years Class I	0	6	Normal (minus)	80	0.009	Adequate	Normal (minus)
Stone block (concrete base)	2	Class II	Adequate	6.5	15 years Class II	0	3	Very low	75	0.008	Adequate	High
Brick cubes (macadam base)	10.3	Class II	Low	13.0	7 years Class II	100	7	High	300	0.032	Low	High

Column 5 is one-half of normal life which expresses normal conditions for average age figures.

Column 7 = $\frac{100}{\text{Normal life}}$

NOTE.—The outstanding feature of this tabulation is the large percentage needing resurfacing which show that the funds for renewals have been consistently inadequate and that we are loosing ground each year, as regards the general condition of the system.

[1] Columns 3 to 7 would indicate that the reported maintenance cost should be high for waterbound macadam. As a matter of fact actual expenditures are low as the maintenance budget estimates are consistently reduced below the amount required as the funds are short the main roads are given preference and the waterbound type (largely on secondary roads) have to get along with less expenditure than they are entitled to.

[2] The large per cent requiring renewal at a short age is due to poor original construction (overburned mix).

TABLE 32.—APPROXIMATE MILEAGE AND AGE UNDER DIFFERENT TRAFFIC CLASSIFICATIONS DIVISION 7, JAN., 1923

Traffic classification	Total miles	Average age	Mileage at different ages, years (Jan., 1923)																				
			0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	20	21
Gravel pavement (bituminous seal coat)																							
Class I																							
Class IIA																							
Class II																							
Class III	5.3	6.1						2.4		2.9													
Waterbound macadam (bituminous seal coat)																							
Class I	4.5	12.7					1.0						0.2		2.0								1.3
Class IIA	51.5	8.5					5.5	5.3	9.3	10.0			1.0		15.1	3.5	0.3	1.5					
Class II	177.3	8.4			8.9	0.3	17.3	12.0	21.9	21.5	17.9		14.4	10.3	5.2	11.4	16.9	13.5	4.5				
Class III	158.3	7.1	23.3	3.3		11.6	3.4	10.4	24.3	20.3	15.5		0.5	2.7	10.5	18.2	7.9	2.7	3.7			1.3	
Penetration bituminous macadam																							
Class I	33.9	7.9				0.2	8.9	3.6	1.9		3.2		8.8		7.3								
Class IIA	45.8	8.0			0.4	2.6	10.6		1.0	1.4	0.8	1.4	12.1	10.5	5.0								
Class II	105.6	7.7	12.6	3.0	2.7	5.4	1.2	3.4	3.6	8.2	11.5	8.2	1.2	28.8	14.1	1.7							
Class III	52.9	9.0		0.3		0.5	2.7	1.2	3.4	1.4		19.2	11.6	8.7	2.2	1.7							
Asphaltic concrete, macadam base (Total mileage not entirely covered in this table)																							
Class I	4.1	7.5		0.2			0.5	0.8		1.5					1.1								
Class IIA	9.6	5.0		0.3	0.7	2.4		4.6		0.6		0.1			0.9								
Class II	2.8	6.8		0.9				0.8							1.1								
Class III	0.6	3.0		0.4					0.2														
Asphaltic concrete, concrete base																							
Class I	8.5	6.4			2.3	1.1				0.7	1.4		3.0										
Class IIA	12.9	5.0		3.6				4.1	1.4			3.8											
Class II	5.9	8.0		0.3					1.0			4.6											
Class III	10.9	9.0										10.9											
Cement concrete, 1:2:4 mix or better																							
Class I	9.5	3.0		1.6	2.6		3.1	2.1															
Class IIA	38.5	4.0	1.1	15.6		0.3		9.0			12.5												
Class II	31.8	1.0	2.1	20.7	6.3	2.7																	
Class III	35.0	1.4	3.4	22.5	1.5	4.2	3.4																
Brick on concrete base																							
Class I	8.7	8.0						1.0	0.1	1.7	3.1	2.4			0.4								
Class IIA	6.1	7.5							1.1	2.0	2.6	0.2	0.2										
Class II	6.1	8.0							0.6		4.6						0.9						
Class III	1.8	8.0							0.6		0.6	0.6											

Analysis of Maintenance Costs. *Traffic Classification* (Table 32). The basic factor of maintenance costs is volume and character of traffic. Table 32 classifies the roads according to classification map shown in the Frontispiece which was prepared by study of our short-time traffic counts modified by common sense as discussed on page 44 of the first book of this series "Highway Location."

Class I traffic	2,000 or more vehicles daily (10-hour count in summer).
Class IIA traffic	1,500–2,000 (10-hour count in summer).
Class II traffic	800–1,500 (10-hour count in summer).
Class III traffic	300–800 (10-hour count in summer).

The outstanding conclusions from Table 32 are as follows:

1. The maintenance data on the macadam types for this district should be fairly conclusive as there is enough milage at a great enough age to mean something.

2. The maintenance costs for the rigid types are not yet at all conclusive and are probably far under normal considering age and traffic volume.

3. Waterbound macadams are in the main serving slightly more traffic than recommended for this type.

4. Bituminous macadam is apparently serving about the proper volume for this type.

5. Cement concrete is serving considerably less volume than recommended for this type.

6. Brick is serving somewhat less volume than is desirable for this type.

7. Stone block has been selected for footing on steep hills. Volume of traffic has no bearing.

8. Asphaltic concretes are in the main serving somewhat less than a reasonable volume of traffic for this type.

Strength of Existing Pavements Division 7.—According to the best judgment of the engineering force in the division based on observation of the resistance of the existing pavements to traffic action the strength of the different types may be classed as follows:

Waterbound macadam	Noticeably weak due to a large mileage of old thin roads.
Bituminous macadam	Moderately good due to a larger per cent of more recent design.
Asphaltic concretes on macadam	Moderately good.
Asphaltic concretes on concrete	Adequate with a few exceptions.
Cement concrete (1:2:4 mix or better)	Slightly low.
Brick on concrete	Adequate.
Stone block on concrete	Adequate.

These results appear in Column 3, Table 31, page 396.

Recent designs which approximate the recommended depths developed in Chap. II seem adequate for traffic.

Effect of Traffic Volume.—Records in this regard are meager. Table 33, Division 7 and 33A (New York State) shows a start along these lines but the figures are not very convincing as records of soil conditions, adequate original strength, and relative age of pavements are not considered and the finance bookkeeping methods were not devised with the idea of enough subdivisions to give extremely accurate records for a tabulation of this kind. It is therefore necessary to use considerable judgment in assigning rational values to this factor of cost. According to our best judgment, a conservative set of yearly maintenance costs under different volumes of traffic for the most used types is given in Tables 30 and 31. One of the outstanding features of Table 33 is the high cost of shoulder maintenance on Class I traffic indicating that 16-ft. width of pavement is poor economy under such traffic.

TABLE 33.—TABULAR COSTS EFFECT OF TRAFFIC SUMMARIZED, DIVISION 7 NEW YORK STATE.

	Mileage	Guard rails, ditches, shoulders, etc., maintenance per mile	Pavement maintenance, 5-year average, 1917–1922	
			Per mile	Per square yard
16-FT. WATERBOUND MACADAM AVERAGE AGE 10 YEARS				
Class I traffic[1]	3.0	$300	$900	$0.095
Class II traffic[1]	36.0	160	950	0.100
Class III traffic	100.0	110	600	0.065
Class IV traffic	64.5	110	600	0.065
16-FT. PENETRATION BITUMINOUS MACADAM AVERAGE AGE 9 YEARS				
Class I traffic[1]	22.3	$250	$340	$0.036
Class II traffic[1]	38.1	200	615	0.065
Class III traffic	29.1	180	400	0.043
Class IV traffic	41.7	120	310	0.034
16-FT. FIRST CLASS CONCRETE AVERAGE AGE 6 YEARS				
Class I traffic	0			
Class II traffic	17.55	$100	$37	$0.004
Class III traffic	8.6	170	10	0.001
Class IV traffic	3.5	140	21	0.002
16-FT. BRICK AVERAGE AGE 9 YEARS				
Class I traffic	0			
Class II traffic	3.4	$150	$ 91	$0.01
Class III traffic	4.4	80	161	0.017
Class IV traffic	0			
16-FT. ASPHALTIC CONCRETE, MACADAM BASE AVERAGE AGE 6 YEARS				
Class I traffic[1]	1.1	$210	$930[1]	$0.100[1]
Class II traffic	0.8	130	130	0.014
Class III traffic	0			
Class IV traffic	0			
16-FT. ASPHALTIC CONCRETE, CEMENT CONCRETE BASE AVERAGE AGE 7 YEARS				
Class I traffic[1]	3.2	$170	$530[1]	$0.057[1]
Class II traffic	7.1	160	120	0.013
Class III traffic	7.5	90	140	0.015
Class IV traffic	0			

[1] Includes effect of army truck traffic 1918.

NOTE.—Shoulder maintenance high on Class I as 16-ft. width is too narrow for this volume of traffic.

Division 7, Jan. 25, 1923.

AVERAGE COST OF MAINTENANCE FOR DIFFERENT TYPES OF PAVEMENT FOR PAST FIVE YEARS BY TRAFFIC CLASSIFICATION

Roads having less than 500 vehicles per 12-hour day

Type	Miles, average number 1918 to 1922 inclusive	Average cost per mile 1918 to 1922 inclusive									
		Pavement only					Total expense exclusive of resurfacing or reconstruction				
		1918	1919	1920	1921	1922	1918	1919	1920	1921	1922
Gravel	2.87	$676	$400	$143	$ 564	$294	$750	$502	$244	$ 642	$342
Waterbound macadam	64.46	705	601	449	772	626	784	678	572	887	771
Bituminous macadam, mixed method on macadam base	0										
Bituminous macadam, penetration method	41.68	261	269	185	411	415	332	340	311	581	524
Bituminous macadam, mixed method on concrete base	0										
Second class concrete, Hassam concrete	3.98	779	565	769	1,007	377	822	659	858	1,112	630
Brick	0										
First-class concrete	3.48	None	None	None	6	102	None	None	None	166	546

Division 7, Jan. 25, 1923.

AVERAGE COST OF MAINTENANCE FOR DIFFERENT TYPES OF PAVEMENT FOR PAST FIVE YEARS BY TRAFFIC CLASSIFICATION

Roads having between 500 and 1,000 vehicles per 12-hour day

Type	Miles, average number 1918 to 1922 inclusive	Average cost per mile 1918 to 1922 inclusive									
		Pavement only					Total expense exclusive of resurfacing or reconstruction				
		1918	1919	1920	1921	1922	1918	1919	1920	1921	1922
Gravel	0										
Waterbound macadam	100.44	$634	$550	$579	$613	$596	$721	$ 643	$688	$702	$764
Bituminous macadam, mixed method on macadam base	0										
Bituminous macadam, penetration method	29.09	541	326	394	261	439	637	424	645	420	680
Bituminous macadam, mixed method on concrete base	7.46	186	29	11	108	376	268	121	88	159	495
Second-class concrete, Hassam concrete	6.05	766	978	36	49	104	888	1,095	296	183	248
Brick	4.35	61	286	53	369	40	272	365	130	403	55
First-class concrete	8.61	0	13	4	4	36	66	83	72	286	374

Divison 7, Jan. 25, 1923.

AVERAGE COST OF MAINTENANCE FOR DIFFERENT TYPES OF PAVEMENT FOR PAST FIVE YEARS BY TRAFFIC CLASSIFICATION

Roads having between 1,000 and 2,000 vehicles per 12-hour day

Type	Miles, average number 1918 to 1922 inclusive	Average cost per mile 1918 to 1922 inclusive									
		Pavement only					Total expense exclusive of resurfacing or reconstruction				
		1918	1919	1920	1921	1922	1918	1919	1920	1921	1922
Gravel	0										
Waterbound macadam	35.77	$2,709	$528	$422	$589	$541	$2,789	$621	$584	$802	$793
Bituminous macadam, mixed method on macadam base	0.78	0	0	71	350	208	0	0	340	390	560
Bituminous macadam, penetration method	38.12	1,540	547	228	400	363	1,625	634	504	638	618
Bituminous macadam, mixed method on concrete base	7.10	56	32	140	192	165	98	135	267	697	209
Second-class concrete, Hassam concrete	6.54	1,383	144	84	287	398	1,574	243	150	520	552
Brick	3.42	218	139	27	29	41	378	217	98	256	242
First-class concrete	17.55	36	28	21	33	68	108	106	96	162	193

Division 7, Jan. 25, 1923.

AVERAGE COST OF MAINTENANCE FOR DIFFERENT TYPES OF PAVEMENT FOR PAST FIVE YEARS BY TRAFFIC CLASSIFICATION

Roads having over 2,000 vehicles per 12-hour day

Type	Miles, average number 1918 to 1922 inclusive[1]	Average cost per mile 1918 to 1922 inclusive									
		Pavement only					Total expense exclusive of resurfacing or reconstruction				
		1918	1919	1920	1921	1922	1918	1919	1920	1921	1922
Gravel	0										
Waterbound macadam	2.95	$ 773	$519	$793	$2,009	$383	$ 873	$619	$1,041	$2,465	$911
Bituminous macadam, mixed method on macadam base	1.07	4,250	356	9	39	0	4,350	455	424	470	517
Bituminous macadam, penetration method	22.27	605	255	108	359	371	704	355	255	567	567
Bituminous macadam, mixed method on concrete base	3.20	1,733	330	161	227	199	1,767	418	254	500	571
Second-class concrete, Hassam concrete	0										
Brick	0										
First-class concrete	0										

[1] Army truck traffic.

TABLE 33A.—TABLES SHOWING AVERAGE COST OF MAINTENANCE OF VARIOUS TYPES OF PAVEMENT CLASSIFIED ACCORDING TO THE AMOUNT OF TRAFFIC

1918 to 1922 inclusive (New York State)

Amount of traffic per 12-hour day summer months	Miles		Cost of maintenance per mile per year	
			Pavement only	Total maintenance
Gravel Pavement				
Less than 500	110.76		$584	$737
500 to 1,000	31.49		721	924
1,000 to 2,000	6.62		675	872
Over 2,000	0.60		824	983
Total	149.47	Average	$622	$785
Waterbound Macadam				
Less than 500	1,111.72		$551	$658
500 to 1,000	763.26		652	843
1,000 to 2,000	360.12		692	897
Over 2,000	38.51		881	1,110
Total	2,273.61	Average	$615	$766
Bituminous Macadam, Penetration Method				
Less than 500	947.41		$303	$429
500 to 1,000	1,050.61		355	499
1,000 to 2,000	798.03		409	612
Over 2,000	317.09		646	889
Total	3,113.14	Average	$382	$547
Mixed Bituminous Macadam on Macadam Base				
Less than 500	12.87		$375	$473
500 to 1,000	5.90		513	612
1,000 to 2,000	7.48		302	484
Over 2,000	17.89		544	913
Total	44.14	Average	$449	$673
Mixed Bituminous Macadam on Concrete Base				
Less than 500	7.66		$ 99	$300
500 to 1,000	22.65		146	231
1,000 to 2,000	30.39		146	298
Over 2,000	29.02		229	336
Total	89.72	Average	$169	$293
Hassam Pavement and Second Class Concrete				
Less than 500	47.79		$532	$759
500 to 1,000	84.71		495	675
1,000 to 2,000	57.97		545	768
Over 2,000	21.88		474	728
Total	212.35	Average	$517	$724
Brick Pavement				
Less than 500	31.35		$165	$414
500 to 1,000	64.33		99	199
1,000 to 2,000	62.69		109	219
Over 2,000	87.77		279	493
Total	246.14	Average	$174	$337
First Class Concrete Pavement 1:2:4 or better				
Less than 500	114.61		$ 62	$172
500 to 1,000	158.28		54	152
1,000 to 2,000	199.46		76	226
Over 2,000	98.28		149	402
Total	570.63	Average	$ 80	$230
Total of Above Types				
Less than 500	2,384.17		$422	$543
500 to 1,000	2,181.23		438	595
1,000 to 2,000	1,522.76		422	618
Over 2,000	611.04		495	735
Total	6,699.20	Average	$433	$595

TABLE SHOWING COST OF MAINTENANCE OF MIXED BITUMINOUS MACADAM ON MACADAM BASE, CLASSIFIED ACCORDING TO TRAFFIC

Traffic less than 500 per 12-hour day

Division	Miles	Cost of maintenance per mile per year exclusive of reconstruction	
		Pavement only	Total maintenance
1	1.20	$ 80	$229
9	11.67	405	498
Total.....	12.87	Average..... $375	$473

(No pavement under this classification in Division 2, 3, 4, 5, 6, 7, 8)

500 to 1,000

1	0.38	$ 61	$110
9	5.52	544	647
Total.....	5.90	Average..... $513	$612

(No pavement under this classification in Division 2, 3, 4, 5, 6, 7, 8)

1,000 to 2,000

1	2.31	$629	$879
2	1.23	192	350
3			
4			
5	2.16	209	303
6			
7	0.78	126	258
8			
9	1.00	84	315
Total.....	7.48	Average..... $302	$484

Over 2,000

1	0.52	$402	$1,212
2			
3			
4	10.99	729	1,216
5	1.41	232	326
6			
7	1.07	931	1,243
8			
9	3.90	50	134
Total.....	17.89	Average..... $544	$ 913

COST OF MAINTENANCE OF BITUMINOUS MACADAM, MIXED METHOD ON CONCRETE CLASSIFIED ACCORDING TO TRAFFIC

Traffic less than 500 per 12-hour day

Division	Miles	Cost of maintenance per mile per year exclusive of reconstruction	
		Pavement only	Total maintenance
1	1.73	$ 93	$503
2	0.89	28	580
3			
4	1.34	8	9
5			
6			
7			
8	3.70	153	242
9			
Total.....	7.66	Average..... $ 99	$300
500 to 1,000			
1			
2	1.68	$723	$862
3	2.39	55	150
4	2.37	61	67
5	0.36	0	0
6			
7	7.46	142	226
8	8.39	88	189
9			
Total.....	22.65	Average..... $146	$231
1,000 to 2,000			
1	11.58	$ 69	$232
2	7.88	217	318
3			
4	0.42	47	56
5			
6	3.41	317	527
7	7.10	117	282
8			
9			
Total.....	30.39	Average..... $146	$298
Over 2,000			
1			
2	1.19	$ 7	$ 8
3			
4	10.91	421	485
5	0.51	222	270
6	13.10	16	154
7	3.20	530	703
8			
9			
Total.....	29.02	$229	$336

TABLE 33A.—SHOWING COST OF MAINTENANCE OF SECOND-CLASS CONCRETE AND HASSAM PAVEMENT CLASSIFIED ACCORDING TO THE AMOUNT OF TRAFFIC

Division	Miles	Cost of maintenance per mile per year exclusive of reconstruction	
		Pavement only	Total maintenance
Traffic less than 500 per 12-hour day			
1			
2	6.27	$503	$729
3			
4	8.27	471	590
5	8.05	304	467
6			
7	3.98	700	816
8	7.24	488	875
9	13.98	749	963
Total	47.79	Average $532	$759
500 to 1,000			
1	8.77	$371	$474
2	2.01	299	412
3	4.04	109	128
4			
5	3.98	340	494
6	13.57	447	560
7	6.05	487	542
8	41.09	562	820
9	5.20	767	979
Total	84.71	Average $495	$675
1,000 to 2,000			
1	9.38	$230	$506
2	8.28	646	916
3			
4			
5	7.75	359	435
6	4.34	293	623
7	6.54	460	607
8	10.60	720	940
9	11.08	849	1,094
Total	57.97	Average $545	$ 768
Over 2,000			
1	0.00	$000	$ 000
2	4.56	894	1,271
3			
4			
5			
6	9.55	144	384
7			
8			
9	7.77	636	833
Total	21.88	Average $474	$ 728

TABLE 33A.—SHOWING COST OF MAINTENANCE OF BRICK PAVEMENT CLASSIFIED ACCORDING TO THE AMOUNT OF TRAFFIC

Division	Miles	Cost of maintenance per mile per year exclusive of reconstruction	
		Pavement only	Total maintenance
Traffic less than 500 per 12-hour day			
1			
2	6.12	$256	$515
3	1.86	10	17
4	1.02		
5	0.88	30	46
6			
7			
8	4.83	32	208
9	16.64	205	527
Total.....	31.35	Average..... $165	$415
500 to 1,000			
1			
2	3.92	4	23
3	6.10	30	43
4	0.39		
5	0.44	42	80
6			
7	4.35	162	245
8	10.49	95	210
9	38.64	114	236
Total.....	64.33	Average..... $ 99	$199
1,000 to 2,000			
1	2.92	$137	$172
2	3.26	71	208
3	0.49	18	26
4	0.82	184	204
5	1.84	57	70
6	1.06	32	32
7	3.42	91	240
8	5.68	33	60
9	43.20	125	256
Total.....	62.69	Average..... $109	$219
Over 2,000			
1	8.07	$196	$400
2	9.98	226	349
3			
4	3.15	95	106
5	1.43	72	94
6	3.33	128	203
7			
8	3.69	86	131
9	58.12	336	598
Total.....	87.77	Average..... $279	$493

TABLE 33A.—SHOWING COST OF MAINTENANCE OF GRAVEL TYPE OF PAVEMENT CLASSIFIED ACCORDING TO THE AMOUNT OF TRAFFIC

Traffic less than 500 per 12-hour day

Division	Miles	Cost of maintenance per mile per year exclusive of reconstruction	
		Pavement only	Total maintenance
1	51.40	$663	$ 790
2	24.21	662	935
3	6.38	332	363
4	9.04	470	588
5	4.71	500	548
6			
7	2.87	415	496
8	12.15	387	545
9			
Total.....	110.76	Average..... $584	$ 737

500 to 1,000

1	19.16	$768	$ 947
2	5.47	325	358
3			
4			
5			
6	1.20	683	988
7			
8	5.66	970	1,420
9			
Total.....	31.49	Average..... $721	$ 924

1,000 to 2,000

1	3.60	$777	$ 918
2	3.02	547	812
Total.....	6.62	Average..... $675	$ 872

(No pavement under this classification in Division 3, 4, 5, 6, 7, 8, 9)

Over 2,000

1	0.60	$824	$ 983
Total.....	0.60	Average..... $824	$ 983

(No pavement under this classification in Division 2 to 9 inclusive.)

TABLE 33A.—SHOWING COST OF MAINTENANCE OF WATERBOUND MACADAM TYPE OF PAVEMENT CLASSIFIED ACCORDING TO AMOUNT OF TRAFFIC

Traffic less than 500 per 12-hour day

Division	Miles	Cost of maintenance per mile per year exclusive of reconstruction	
		Pavement only	Total maintenance
1	149.99	$ 518	$ 653
2	196.46	497	663
3	76.07	789	869
4	181.57	447	596
5	136.73	643	727
6	35.56	694	883
7	64.46	631	738
8	188.22	509	711
9	92.66	580	770
Total.....	1,111.72	Average.....$ 551	$ 658
500 to 1,000			
1	124.42	$ 722	$ 932
2	128.07	671	914
3	55.47	807	895
4	109.20	630	841
5	130.27	579	679
6	5.86	612	680
7	100.44	596	704
8	102.28	632	894
9	7.25	524	639
Total.....	763.26	Average..... $652	$ 843
1,000 to 2,000			
1	79.67	$ 769	$ 957
2	48.31	762	1,070
3	29.19	592	661
4	19.07	692	922
5	36.30	385	480
6	27.31	590	795
7	35.77	957	1,118
8	81.64	591	950
9	12.86	1,049	1,415
Total.....	360.12	Average.... $ 692	$ 897
Over 2,000			
1	14.63	$ 980	$ 1,212
2	2.27	616	904
3			
4	9.31	737	982
5	0.68	684	762
6	0.53	872	1,111
7	2.95	895	1,182
8	8.14	943	1,148
9			
Total.....	38.51	Average.....$ 881	$ 1,110

TABLE 33A.—SHOWING COST OF MAINTENANCE OF BITUMINOUS MACADAM. PENETRATIVE METHOD OF PAVEMENT CLASSIFIED ACCORDING TO TRAFFIC

Traffic less than 500 per 12-hour day

Division	Miles	Cost of maintenance per mile per year exclusive of reconstruction	
		Pavement only	Total maintenance
1	118.63	$289	$ 448
2	179.10	357	567
3	244.67	290	337
4	100.82	283	377
5	134.37	292	414
6	35.68	193	361
7	41.68	308	428
8	52.39	251	415
9	40.07	440	568
Total.....	947.41	Average..... $303	$ 429
500 to 1,000			
1	187.42	$396	$ 563
2	167.23	346	538
3	263.55	321	375
4	100.93	338	453
5	123.75	380	538
6	66.55	251	378
7	29.09	392	561
8	81.69	458	751
9	30.40	342	527
Total.....	1,050.61	Average..... $355	$499
1,000 to 2,000			
1	243.60	$456	$ 683
2	166.25	445	739
3	58.90	214	250
4	78.74	278	370
5	85.93	439	562
6	63.59	317	527
7	38.12	616	840
8	21.29	305	472
9	41.61	457	676
Total.....	798.03	Average..... $409	$ 612
Over 2,000			
1	109.06	$746	$1,027
2	83.62	642	974
3			
4	40.88	500	666
5	24.28	384	508
6	24.07	792	1,011
7	22.27	340	490
8	8.14	944	1,148
9	4.77	461	732
Total.....	317.09	Average..... $646	$ 889

TABLE 33A.—SHOWING COST OF MAINTENANCE OF FIRST-CLASS CONCRETE CLASSIFIED ACCORDING TO THE AMOUNT OF TRAFFIC

Division	Miles	Cost of maintenance per mile per year exclusive of reconstruction	
		Pavement only	Total maintenance
Traffic less than 500 per 12-hour day			
1	11.91	$ 42	$ 85
2	9.77	10	248
3	36.86	37	88
4	15.58	77	154
5	0.88	30	46
6	3.70	32	293
7	3.48	52	356
8	1.97	222	796
9	30.46	106	225
Total.....	114.61	Average..... $ 62	$ 172
500 to 1,000			
1	23.26	$ 79	$ 203
2	24.23	98	186
3	18.57	11	62
4	5.57	77	154
5	11.28	28	80
6	8.11	26	125
7	8.61	9	176
8	1.98	402	1,031
9	56.67	41	130
Total.....	158.28	Average..... $ 54	$ 152
1,000 to 2,000			
1	63.08	$102	$ 354
2	19.01	52	190
3	3.54	2	3
4	5.77	77	154
5	5.76	33	69
6	5.65	24	182
7	17.55	37	133
8	3.47	2	110
9	76.23	82	227
Total.....	199.46	Average..... $ 76	$ 226
Over 2,000			
1	45.25	$146	$ 431
2	12.56	249	414
3			
4			
5	0.47	190	310
6	2.85	150	425
7			
8			
9	37.15	143	361
Total.....	98.28	Average..... $149	$ 402

Life of Pavements. *Macadam Pavements.*—Division 7 data on durability of these pavements is reliable. Table 34 gives the age at which actual reconstruction has occurred. This table is interesting but not conclusive as the records apply to the weaker roads under exceptional traffic which tends to shorten the age reported. On the other hand, these roads were permitted to remain in poor condition for from 2 to 4 years beyond the time at which they actually needed resurfacing. This data gives the average age for Waterbound Macadam as 8.9 years and Bituminous Macadam as 8.4 years, Topeka on concrete at 7 years and Second Class Concrete (1:2½:5 Mix) at 6.5 years). These results are inconclusive unless verified by supplementary data.

TABLE 34.—SHOWING AGE AT TIME OF ACTUAL RECONSTRUCTION

Age in years	Waterbound macadam			Bituminous macadam penetration method			Bituminous macadam mixing method concrete base			Second class concrete and Hassam concrete		
	Total resurfacing = 173 miles			Total resurfacing = 43.6 miles			Total resurfacing = 1.22 miles			Total resurfacing = 20.46 miles		
	Mileage rebuilt	Percentage of total	Accumulated percentage of total	Mileage rebuilt	Percentage of total	Accumulated percentage of total	Mileage rebuilt	Percentage of total	Accumulated percentage of total	Mileage rebuilt	Percentage of total	Accumulated percentage of total
3	0.30	0.2	0.2	.....	.....	.....	.....	.....	.....	0.65	3.2	3.2
4	20.86	12.1	12.3	2.28	5.2	5.2	.....	.....	.....	4.29	21.0	24.2
5	5.94	3.4	15.7	0.77	1.8	7.0	.....	.....	.....	3.53	17.2	41.4
6	16.13	9.2	24.9	5.13	11.8	18.8	0.40	32.8	32.8	1.14	5.6	47.0
7	13.80	8.0	32.9	8.81	20.2	39.0	.....	.....	.....	2.31	11.3	58.3
8	22.33	12.9	45.8	7.55	17.3	56.3	.....	.....	.....	5.62	27.4	85.7
9	26.90	15.6	61.4	2.92	6.7	63.0	0.82	67.2	100.0	1.92	9.4	95.1
10	15.05	8.7	70.1	2.81	6.4	69.4	.....	.....	.....	1.00	4.9	100.0
11	19.74	11.4	81.5	11.21	25.7	95.1						
12	4.44	2.6	84.1	2.12	4.9	100.0						
13	11.48	6.5	90.6									
14	9.46	5.5	96.1									
15	2.38	1.4	97.5									
16												
17	2.15	1.2	98.7									
18												
19	2.20	1.3	100.0									

Table 35 gives the mileage of the different types which need resurfacing at their present reported age. This data is fairly reliable in determining range of life and probable maximum. According to these tables

TABLE 35.—APPROXIMATE PERCENTAGE OF MILEAGE WHICH NEEDS RESURFACING AT DIFFERENT AGES

Present age in years Jan., 1923	Waterbound macadam		Penetration bituminous macadam		Asphaltic concrete on macadam base		Asphaltic concrete concrete base		Second-class concrete		Gravel	
	Total miles at each age Column 1	Per cent of Column 1 which needs resurface	Miles	Per cent	Miles	Per cent	Miles	Per cent	Miles	Per cent	Miles	Per cent
1	26.3	0	15.9	0	1.8	0	3.9	0				
2	8.9	0	3.1	0	0.7	0	2.3	0				
3	11.9	0	8.7	0	2.4	0	1.1	0				
4	27.2	11	23.4	0	0.5	0	....	..	0.3	0		
5	27.7	30	8.2	6	6.2	30	4.1	25	1.66	100	2.4	100
6	55.5	25	9.9	20	0.2	0	2.4	0				
7	51.8	50	11.0	35	2.1	0	0.7	0	8.38	100	2.9	0
8	33.4	60	15.5	24	...	..	1.4	0				
9	....	...	28.8	30	...	..	19.3[1]	75	6.36	100		
10	16.1	100	33.7	30	...	..	3.0	0	4.14	100		
11	13.0	100	48.0	68								
12	32.8	100	28.6	78	3.1	30						
13	33.1	100	3.4	50								
14	25.1	100										
15	17.7	100										
16	8.2	100										
17												
18												
19												
20	1.3	100										
21	1.3	100										
Modifying conditions and conclusions.	Average traffic Class II Pavements rather weak considering soil and traffic. Range in durability 4 to 10 years. Reasonable life for Class II for well designed road probably 8 to 10 years.		Average traffic Class II Pavement a little under adequate strength. Range in durability 6 to 15 years. Reasonable life for Class II traffic well designed pavements probably 10 to 12 years.		Average traffic Class I *Data not conclusive.*		Poor construction. Overburned mixture. *Data not conclusive.*		Class II traffic. Poor type of pavement. Reasonable life less than 5 years.		*Data not conclusive.*	

supplemented by judgment in regard to modifying conditions we place the reasonable life of the macadam base pavements as follows:

These ages are somewhat less than usually adopted due to the fact that they are based on a maximum permissible Vialog coefficient of roughness of 250 ft. per mile without excessive yearly maintenance expenditures. This limit of roughness is somewhat less than has heretofore been customary but we are convinced that on the main roads it is desirable to avoid the extreme roughness often tolerated for the last 3 to 5 years before reconstruction is commonly resorted to. The age before reconstruction can be increased by excessive maintenance expenditures but this has little effect on total cost of the combined items of maintenance and renewal; what is spent on one is saved on the other.

Table of Estimated Reasonable Life Flexible Base Pavements

	Waterbound macadam	Bituminous macadam	Asphaltic concrete on macadam base
Class I traffic	Not suitable	6 to 12 years	8 to 14 years
Class II traffic	8 to 12 years	10 to 13 years	10 to 15 years
Class III traffic	10 to 13 years	12 to 15 years	Not advised
Class IV traffic[1]	12 to 15 years	Not advised	Not advised

[1] Class IV is a very indefinite condition.

Table 30 uses the low limit. Under really good conditions of design and maintenance the upper limit can be used and even extended a few years.

Life of Rigid Base Pavements.—The durability of rigid base pavements on heavy traffic rural highways cannot be very definitely settled as yet as there are not enough miles of sufficient age to develop reliable data. Rural highway conditions are considerably different from city street conditions due to concentration of traffic along an unprotected pavement edge and poor subsoil drainage systems on Rural Roads. City records are not really up to date on account of changed traffic conditions so that the life assigned to rigid base pavements is at best a careful guess which is controlled by the excellence of construction and maintenance practice for the district under consideration. The values assigned in Table 30 represent the best judgment of our local engineers reinforced by city records and are for moderately good construction and maintenance conditions. The effect of good work on life is shown graphically on page 144, Chap. II. Supporting data is included below by a quotation from Blanchard's Handbook.

TABLE 36.—CONSENSUS OF OPINION OF CANADIAN ENGINEERS AS TO DURABILITY (11*a*)[2]

Pavement	Small repairs, years	Extensive repairs, years	Complete reconstruction, years
Asphalt block	5 to 10	10 to 12	12 to 15
Asphalt concrete	4 to 6	6 to 8[1]	8 to 10[1]
Bitulithic	5 to 8	10 to 15	15 to 20
Brick	8 to 10	10 to 15	15 to 18
Cement-concrete	5 to 8	10 to 12	15 to 18[1]
Scoria block and stone	10 to 15	15 to 20	20 to 30
Sheet-asphalt	4 to 8	10 to 15	15 to 18
Untreated wood block	3 to 5	6 to 10	10 to 12
Treated wood block	8 to 10	12 to 15	15 to 18[1]

[1] These pavements have not attained an age in Canada sufficient to place the figures beyond conjecture.

OPINIONS OF CANADIAN ENGINEERS AS TO NATURE OF DETERIORATION (11*a*).

"ASPHALT BLOCK: Edge-wear forming holes and cobbles; worn pavement noisy and hard to keep clean; disintegration of bottom of blocks.

"ASPHALTIC CONCRETE: Wears in holes; susceptible to marking in hot, sunny weather.

"BITULITHIC: Wears evenly, with a tendency to holes under heavier traffic; susceptible to surface marks in hot weather.

"BRICK: Edge-wear and cobbling under heavy traffic; increased noise and unsanitariness as wear increases; when worn badly it slows down traffic.

"SHEET-ASPHALT: Wears slowly into large holes or patches; heavy traffic causes ruts; cracks hasten deterioration.

"WOOD BLOCK: Rots rapidly if untreated, retarding traffic; treated block wears slowly and evenly; frost intrusion causes buckling.

"STONE AND SCORIA BLOCK: Wears gradually into holes and cobbles; unsanitary when roughened.

"CEMENT-CONCRETE: Wear is slow and even if well placed; cracking and chipping develop otherwise."

[2] "American Highway Engineer's Handbook." John Wiley & Sons, New York, N. Y.

Selected Typical Roads.—The second method of deriving normal costs is the selected road method. Table 37 gives an idea of what can be done if the roads are well designed and maintained as compared with weak design and spasmodic maintenance.

Table 37 shows that firm waterbound macadam can be maintained under Class I traffic for about $0.06 per square yard per year exclusive of renewals. Under Class II traffic for about $0.035 but that weak design under even Class III traffic will raise the maintenance to about $0.06.

Firm bituminous penetration can be maintained under Class I for $0.035 for a long term of years (see road 5021). Under Class II traffic for about 0.015 to 0.030 but if the foundation is weak it jumps up to around $0.045 (Road 5271).

TABLE 37.—SELECTED ROADS. AVERAGE MAINTENANCE COSTS PER YEAR FOR A PERIOD OF 4 TO 5 YEARS (1918 TO 1922)
(Renewal costs not included as none of these roads have yet been resurfaced)

Road No.	Type	Traffic classification	Age, years	Foundation strength	Length, miles	Width, feet	Cost per mile shoulders	Cost per mile pavement	Cost per square yard pavement	Remarks
61	Waterbound macadam—oiled	Class I	21	Adequate	1.30	16	$ 25	$585	$0.062	Needs reconstruction
810	Waterbound macadam—oiled	Class IIA	8	Adequate	1.03	16	198	308	0.033	Perfect condition
648	Waterbound macadam—oiled	Class IIA	7	Adequate	7.37	16	94	284	0.030	Good condition
403	Waterbound macadam—oiled	Class III	14	Adequate	2.07	14	52	434	0.053	Good condition
492	Waterbound macadam—oiled	Class III	11	Poor	5.75	16	35	250	0 027	Poor condition
5507	Waterbound macadam—oiled	Class III	7	Adequate	2.14	16	71	379	0.040	Good condition
1290	Waterbound macadam—oiled	Class III	7	Poor	1.53	12	152	397	0.057	Fair condition
5021	Penetration bituminous macadam	Class I	12	Adequate	3.98	16	139	335	0.035	Good condition
5046	Penetration bituminous macadam	Class IIA	11	Moderate	5.75	16	198	350	0.037	Moderately good
62	Penetration bituminous macadam	Class IIA	10	Adequate	6.15	16	55	227	0.024	Good condition
495	Penetration bituminous macadam	Class II	10	Adequate	6.15	16	38	119	0.013	Good condition
5271	Penetration bituminous macadam	Class II	8	Weak	5.51	16	80	435	0.046	Fair condition
502	Penetration bituminous macadam	Class III	10	Adequate	5.20	14	159	119	0.014	Good condition
80	Penetration bituminous macadam	Class III	13	Weak	3.60	16	27	164	0.018	Poor condition
63	Asphaltic concrete—macadam base	Class I	7	Moderate	1.50	16	115	139	0.015	Good condition
253	Asphaltic concrete—macadam base	Class IIA	5	Adequate	0.75	16	495	0	0.0	Excellent condition
5	Asphaltic concrete—macadam base	Class I	12	Adequate	1.07	16	90	80	0.009	Good condition
5	Asphaltic concrete—cement concrete base	Class I	8	Moderate	1.39	16	152	127	0.013	Fair condition
538	Asphaltic concrete—cement concrete base*	Class I	10	Moderate	3.40	16	60	459	0.050	Fair condition
5302	Asphaltic concrete—cement concrete base	Class IIA	5	Adequate	3.88	16	366	172	0.018	Excellent condition
634	Asphaltic concrete—cement concrete base	Class II	9	Moderate	3.22	15	20	157	0.017	Poor condition
5279	Asphaltic concrete—cement concrete base	Class III	9	Weak	6.14	16	26	183	0.019	Poor condition
1328	Asphaltic concrete—cement concrete base	Class I	7	Adequate	0.73	16	0	75	0.008	Good condition
5421	Cement concrete—1:2:4 mix or better	Class IIA	8	Adequate	0.80	16	110	151	0.016	Excellent condition
5425	Cement concrete—1:2:4 mix or better	Class IIA	8	Moderate	3.24	16½	89	30	0.003	Fair condition
5423	Cement concrete—1:2:4 mix or better	Class II	8	Adequate	6.02	16	128	8	0.001	Good condition
6	Cement concrete—1:2:4 mix or better	Class I	5	Adequate	1.54	16	52	70	0.007	Good condition
5469	Cement concrete—1:2:4 mix or better	Class IIA	5	Adequate	8.95	16	58	27	0.003	Good condition
1499A	Cement concrete—1:2:4 mix or better	Class III	1	Moderate	4.56	16	22	10	0.001	Good condition
172	Brick on concrete base (cement grouted joints)	Class I	7	Adequate	0.66	16	112	56	0.006	Good condition
401	Brick on concrete base (cement grouted joints)	Class IIA	14	Adequate	0.86	16	56	56	0.006	Fair condition
6	Brick on concrete base (cement grouted joints)	Class I	8	Adequate	0.32	16	0 Village	131	0.013	Good condition
5435	Brick on concrete base (cement grouted joints)	Class I	8	Adequate	0.94	16	0 streets	79	0.008	Good condition
1430	Brick on concrete base (cement grouted joints)	Class I	5	Adequate	1.33	16	0 curbed	54	0.006	Good condition

*Poor asphaltic mix on construction.

Asphaltic concretes on firm macadam base under Class IIA traffic have been maintained for a long term for from $0.009 to $0.015 per square yard per year exclusive of renewals. The maintenance cost for these roads is about the same as for the same surface on a cement concrete base.

The data on cement concrete and brick is not conclusive on account of short age of pavements of which we have definite data in comparison with their probable life.

TABLE 38.—NEW YORK STATE MAINTENANCE COSTS (1921)

Type of pavement	Miles maintained		Cost per mile		
	Including change to more durable type	Excluding change to more durable type	Including change to more durable type	Excluding change to more durable type	Pavement only, excluding change to more durable type
Bituminous macadam, penetration method, macadam base, asphalt binder	3,201.87	3,186.82	$1,033	$ 770	$ 581
Tar binder	255.06	255.03	543	540	341
Concrete base, asphalt binder	45.21	45.21	560	560	446
Tar binder	16.81	16.81	363	363	250
Waterbound macadam	2,599.04	2,536.29	2,007	951	813
First-class concrete, 1:2:4 mix or richer	730.45	730.45	225	225	81
Second-class concrete, 1:2½:5 mix or leaner	187.65	181.50	1,957	874	710
Hassam concrete	49.03	49.03	679	679	395
Brick pavement	280.45	280.19	352	307	226
Gravel	141.14	136.30	1,861	890	767
Bituminous macadam:					
Mixed method, Topeka concrete base	65.42	65.01	831	299	128
Topeka, macadam base	29.72	29.72	769	769	354
Amiesite, concrete base	6.25	6.25	440	440	215
Amiesite, macadam base	4.88	4.88	53	53	10
Open mixed, concrete base	17.09	17.09	413	413	166
Open mixed, macadam base	15.43	14.68	3,869	462	288
Bitulithic, concrete base	15.12	15.12	244	244	231
Warrenite-bitulithic	1.81	1.81			
Willite, concrete base	1.66	1.66			
Bitoslag, concrete base	2.31	2.31	37	37	
Sheet asphalt, concrete base	0.61	0.61	229	229	229
Gravel mixed, gravel base	8.38	7.72	5,154	1,978	1,757
Henderson, macadam base	0.51	0.51			
Block pavements:					
Asphalt, concrete base	18.34	18.34	347	347	214
Asphalt, macadam base	1.73	1.73	1,271	1,271	1,082
Wood	0.26	0.26			
Stone	3.58	3.58	9	9	
Brick cubes, macadam base	0.32	0.32	104	104	104
Bituminous sub-base	15.70	15.70	332	332	266
Bituminous macadam, three-layer method	7.29	7.29	734	734	448
Kentucky rock, asphalt	17.55	17.55	686	686	614
Rocmac	0.15	0.15			
Three strip dual	6.81	6.81	134	134	120
Two strip dual	33.99	31.69	1,562	332	146
Total	7,781.62	7,688.42			
Average cost per mile	.....	.....	$1,280	$ 744	$ 582

AVERAGE ANNUAL MAINTENANCE COST PER MILE OF PRINCIPAL TYPES FOR THE PAST 7 YEARS, EXCLUDING CHANGE OF TYPE

	1915	1916	1917	1918	1919	1920	1921	Average
Bituminous macadam, penetration method, asphalt and tar	$ 510	$ 483	$ 408	$ 557	$501	$590	$753	$543
Topeka on concrete base	.....	205	245	435	144	335	299	277
Topeka on macadam base	.....	256	393	1,056	443	985	769	650
Waterbound macadam	1,055	906	970	739	694	797	951	873
Brick	190	176	222	251	247	242	307	234
First-class concrete	129	141	112	160	214	227	225	173
Second-class concrete	1,050	1,080	1,127	791	761	868	874	936
Gravel	955	587	918	909	771	704	890	819
Average all types	$ 750	$ 651	$ 643	$ 608	$560	$631	$744	

TABLE 38A.—SUPPLEMENTARY EXTENSIONS AND AUTHOR'S COMMENTS
New York Maintenance Costs

Type of pavement	Reported 7 year average per mile	Supplementary comments[2]				
		Approximate cost pavement only		Relation[1] of reported cost to normal cost under proper conditions	Recommended allowance	
		Per mile	Per square yard		Normal condition	Unusually favorable
Penetration bituminous macadam	$543	$400	$0.043	High	0.035	0.025
Topeka on concrete base	277	150	0.016	Normal minus	0.020	0.015
Topeka on macadam base	650	500	0.053	High	0.025	0.020
Waterbound macadam	873	720	0.077	High	0.070	0.060
Brick	234	100	0.011	Normal	0.015	0.010
Cement concrete (1:2:4 or better)	173	50	0.006	Very low	0.015	0.010
Cement concrete (1:2½:5 mix)	936	800	0.085	Normal	Poor	type
Gravel	819	680	0.073	High	0.060	0.030

[1] Considers age, traffic and adequate design strength.
[2] Assuming pavement is used under proper volume of traffic (see page 67).

TABLE 39.—SUMMARY OF MAINTENANCE EXPENDITURES DEC. 1, 1921, TO NOV. 30, 1922

State of Massachusetts

Expenditures by types						Comparison modern and old types			
Type	Cost	Miles	Average cost per mile	Square yards	Average cost per square yard		Modern types	Old types	Totals
Granite block	53.80	1.114	48.294	20,204	0.0026	Length (miles)	773,228	625,777	1,399,005
Cement concrete	11,789.40	96.458	122.223	1,044,399	0.0113	Area (square yards)	8,311,199	5,912,436	14,224,435
Bituminous concrete (asphalt)	19,469.50	163.526	119.060	1,771,329	0.0110	Per cent of area	58.4	41.5	100
Bituminous concrete (tar)	1,251.74	3.528	354.801	37,826	0.0331	Cost	197,898.51	485,485.17	683,383.68
Bituminous macadam (asphalt)	55,603.29	252.677	220.056	2,699,764	0.0206	Per cent of cost	29.0	71.0	100
Bituminous macadam (tar)	109,656.39	255.737	428.786	2,735,921	0.0401	Cost per square yard	0.0238	0.0821	
Bituminous macadam (hot oil)	34,041.54	40.330	844,075	354,001	0.0961				
Waterbound macadam	318,689.60	417.269	763.751	3,989,280	0.0799				
Gravel	107,686.72	152.748	704.930	1,407,036	0.0765				
Dirt road	22,641.50	12.760	1,774.412	137,052	0.1652				
Brick	74.39	0.134	555.149	1,987	0.0374				
Sand and clay (layer)	2,425.81	2.670	908.543	25,067	0.0968				
Wood block	0.00	0.054	0.000	568	0.0000				
Totals	683,383.68	1,399.005	488.478	14,224,434	0.0480				

TABLE 40.—COMPARISON OF MAINTENANCE EXPENDITURES FOR MODERN AND OLD TYPE SURFACES—1921
Commonwealth of Massachusetts, Department of Public Works—Divison of Highways

Modern types

Types	District 1			District 2			District 3			District 4		
	Cost	Miles	Cost square yard	Cost	Miles	Cost square yard	Cost	Miles	Cost square yard	Cost	Miles	Cost square yard
Granite block												
Cement concrete	935.29	15.79	0.00546	346.52	5.106	0.0064	1,821.81	14.58	0.0118	255.81	3.478	0.0070
Bituminous concrete (asphalt)				988.98	12.100	0.0077	2,576.73	20.94	0.0112	2,225.43	21.404	0.0095
Bituminous concrete (tar)												
Bituminous macadam (asphalt)	569.31	4.41	0.01213	6,548.97	18.484	0.0349	15,793.85	41.04	0.0369	6,222.98	48.804	0.0118
Bituminous macadam (tar)	12,300.26	34.96	0.03312	11,238.45	28.119	0.0393	17,461.86	51.78	0.0300	2,086.28	9.118	0.0202
Totals	$ 13,804.86	55.16		$ 19,122.92	63.809		$ 37,654.25	128.34		$10,790.50	82.804	

Old Types

Bituminous macadam (hot-oil)				3,274.49	9.255	0.0394				5,709.25	11.382	0.0499
Waterbound macadam	42,720.88	41.76	0.11602	63,590.98	60.764	0.1179	96,808.48	124.65	0.0858	41,909.43	43.176	0.1061
Gravel	22,543.88	26.98	0.09020	20,382.30	30.001	0.0687	22,611.52	40.58	0.0572	20,089.75	24.405	0.0931
Dirt road	23,101.90	12.75	0.16472									
Brick												
Sand-clay (lay)												
Sand-oil (lay)												
Waterbound macadam (widened)												
Totals	$ 88,366.66	81.49		$ 87,247.77	100.02		$119,420.00	165.23		$67,708.43	78.963	
Sum totals	$102,171.52	136.65		$106,370.69	163.829		$157,074.25	293.57		$78,498.93	161.767	

Modern types

Types	District 5			District 6			District 7		
	Cost	Miles	Cost square yard	Cost	Miles	Cost square yard	Cost	Miles	Cost square yard
Granite block	39.87	1.114	0.00197						
Cement concrete	403.94	6.812	0.005	4,276.72	18.520	0.0218	582.79	6.610	0.0083
Bituminous concrete (asphalt)	3,074.55	17.806	0.014	161.30	2.631	0.0057	9,447.47	85.323	0.0103
Bituminous concrete (tar)	549.78	0.539	0.081						
Bituminous macadam (asphalt)	3,903.54	28.626	0.011	16,942.73	53.688	0.0300	4,089.55	26.518	0.0145
Bituminous macadam (tar)	8,201.54	15.111	0.043	23,599.30	55.369	0.0405	20,053.86	52.232	0.0360
Totals	$16,173.22	70.008	.....	$44,980.05	130.208	.....	$ 34,173.67	170.683	

Old Types

Bituminous macadam (hot-oil)	15,559.97	9.807	0.160	5,687.87	2.670	0.2406	154.93	0.169	0.1039
Waterbound macadam	46,427.62	31.665	0.156	32,491.56	35.497	0.1018	37,916.11	52.991	0.0831
Gravel	2,784.30	3.032	0.068	7,250.40	6.608	0.1246			
Dirt road									
Brick	.....	.....	.....	94.64	0.072	0.1177			
Sand-clay (lay)	.....	.....	.....	.....	.....	.....	1,756.92	2.670	0.0701
Sand-oil (lay)	.....	.....	.....	.....	.....	.....	21,709.23	11.622	0.1848
Waterbound macadam (widened)	.....	.....	.....	.....	.....	.....	21,680.54	61.375	0.0308
Totals	64,771.89	44.504	.....	45,524.47	44.847	.....	83,217.73	128.827	
Sum totals	$80,945.11	114.512	.....	$90,504.52	175.055	.....	$117,391.40	299.51	

	Area, per cent		Cost, per cent	
	Modern	Old	Modern	Old
District 1	43.8	56.2	13.5	86.5
District 2	41.7	58.3	17.9	82.1
District 3	47.8	52.2	24.0	76.0
District 4	55.4	44.6	13.7	86.3
District 5	66.5	33.5	19.9	80.1
District 6	77.1	22.6	49.7	50.3
District 7	58.7	41.3	29.1	70.9

Budget Estimates.—Budget estimates are desirable as they insure a careful consideration of the needs of the situation and tend to produce a better balanced ratio of expenditures over the territory as a whole. The following tabulation shows the schedules used in preparing budgets for Division 7. Patrol costs are figured by an actual itemized patrol layout as shown in Fig. 157. Material and oiling estimates are based on careful field inspection of the conditions on each road modified by previous experience with increases due to winter wear. Equipment is carefully checked up and estimates of additions made. Salaries for supervision and office force can be closely approximated from past records. The total of these schedules becomes the budget estimate. These estimates are prepared for each county. The schedules are interchangeable in amounts as far as expenditure goes within the county which gives the necessary flexibility but funds allotted to one county cannot be transferred to any other county. This restriction gives the necessary stability. At one time an effort was made to hold strictly to expenditures for each schedule such as patrol, materials, equipment, etc. but this was found to be impracticable and the present system was adopted.

Maintenance Methods.—Methods will be treated in two parts: First, High Type Hard Surfaced Pavements, and second, Low Type Earth, Sand Clay and Gravel Roads.

Maintenance Organization (Hard Surfaced Pavements).—A typical organization scheme for high-class state improved systems with extensive mileage is shown in Fig. 156. For a system of this character (Division 7), the work can be effectively handled by a combination of Patrol, Gang Work and Contract Awards. The success of the program requires good judgment in a well-balanced utilization of these different methods supplemented by correct use of materials and equipment.

(*a*) *One-man Patrol with Horse Rig.*—This organization unit is very limited in usefulness for a high grade compact system of heavy traffic roads. It is useful for isolated roads under light traffic. The usual length of patrol is from 3 to 7 miles (see Fig. 157 and 157*A*). The usual price paid for patrolman including horse and rig is about $4.50 per day (1922) for about 200 days per year. In Division 7 which is used for illustrative purposes, only 40 miles out of 860 where maintained by horse patrol in 1922. Patrol of this kind handles minor surface repairs of pavements.

On macadam roads, the equipment used is as follows:

One half cubic yard wagon, pick, mattocks, shovel, broom, tamper, rake, asphalt bucket, scythe, straight edge, special equipment furnished from Division Storehouse for scrapping shoulders, or any special jobs.

Stone, bitumen, etc. delivered in stock piles by special truck gang.

TABLE 41.—MAINTENANCE FUNDS—DIVISION 7. TABLE SHOWING EXPENDITURES AND PERCENTAGE OF SAME TO TOTAL EXPENDITURES, EXCLUDING C AND E FUNDS

Expenditures include schedule appropriations, 10 per cent funds, general funds, and maintenance taxes. Federal aid funds excluded. Expenditures are for calendar year

	1920		1921		1922		1923		1924		1925		1926		Average decimal part	Proposed appropriation for 1921	
	Expenditures	Decimal part	Expenditures	Decimal part	Expenditures	Decimal part	Expenditures	Decimal part	Expenditures	Decimal part	Expenditures	Decimal part	Expenditures	Decimal part		Amount	Decimal part
Sch. A—Salaries	$ 40,573.05	0.1050	$ 49,059.32	0.1041	$		$		$		$		$			$	
Sch. B—Office supplies	756.89	0.0020	657.19	0.0014													
Sch. B—Livery	5,007.70	0.0130	5,613.31	0.0119													
Sch. B—Travel	3,058.43	0.0079	2,756.52	0.0059													
Sch. B—Communication	247.69	0.0006	247.06	0.0005													
Sch. B—Office rent	125.00	0.0003	1,000.00	0.0021													
Sch. B—Advertising, printing	190.35	0.0005															
Sch. B—Purchase trucks, mixers, and other large equipment	1,624.74	0.0042	11,061.96	0.0235													
Sch. B—Purchase war materials																	
Sch. B—Purchase tools	6,011.62	0.0155	8,240.33	0.0175													
Sch. B—Repairs to equipment	8,323.09	0.0215	11,890.84	0.0252													
Sch. B—Insurance for equipment	3,480.18	0.0090	709.08	0.0015													
Sch. B—Storehouse construction	6,416.01	0.0166	3,628.21	0.0077													
Sch. B—Storage rental	1,955.12	0.0051	1,967.44	0.0042													
Sch.																	
Sch. C—Resurface	6,384.29	.....	44,168.98														
Sch. D—Surface treatment	62,078.16	0.1606	116,420.25	0.2470													
Sch. E—Reconstruction	481,013.03	.....	358,530.44														
Sch. F—Foreman, labor, trucks, etc	129,914.73	0.3361	155,883.86	0.3307													
Sch. F—Rental equipment	1,007.50	0.0026	870.75	0.0018													
Sch. F—Supplies for equipment	9,937.74	0.0257	8,284.47	0.0176													
Sch. F—Materials	105,856.62	0.2738	93,046.04	0.1974													
Sch. F—Drainage rights																	
Total—excluding C and E funds	$386,564.53	1.0000	$471,327.63	1.0000													
Total—including C and E funds	$873,961.85	.....	$874,026.15														

Decimal part = $\frac{\text{Schedule expenditure}}{\text{Total expenditure minus C and E}}$ To calculate proposed schedule appropriations for ensuing year multiply (total appropriation minus C and E) by average or proposed decimal part.

Appropriations	1920	1921	1922	1923	1924	1925	1926	
Schedule appropriations (budget)	$755,000.00	$735,520.00	$741,720.00	$	$	$	$	$
10 per cent funds—(used)	64,289.62	85,926.11						
General funds—(interest, etc.)	14,682.54	16,892.69						
Maintenance taxes—towns	33,950.00	34,600.00						
Maintenance taxes—villages	8,318.50	8,479.35						

(*Facing page 422.*)

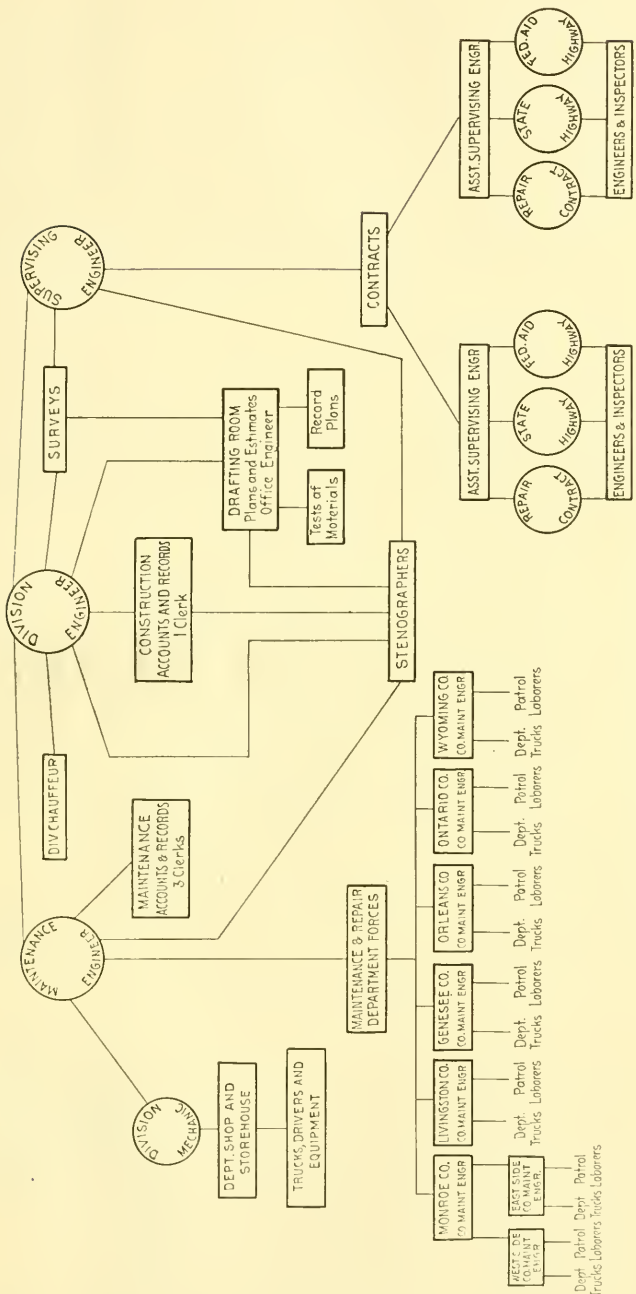


FIG. 156.—Organization chart, Division 7, New York State. Six counties—870 miles of state roads under maintenance.

On rigid pavements, a hook to clean out cracks and necessary chisels, bars, sledges etc. for removing and replacing portions of the pavements.

(*b*) *Small* 1-*ton Truck Patrol* (1 *to* 4 *Men*).—This organization is a very useful and popular unit for maintenance work. It is flexible, speedy and economical. The usual length of patrol ranges from 15 to 25 miles (see Figs. 157 and 157*A*). The usual price paid for patrolman including truck is about $7.50 per day (1922). The usual price for extra helpers is from $0.35 to $0.50 per hour. These patrols work about 200 days a year in northern climates. They take care of minor surface repair of pavements

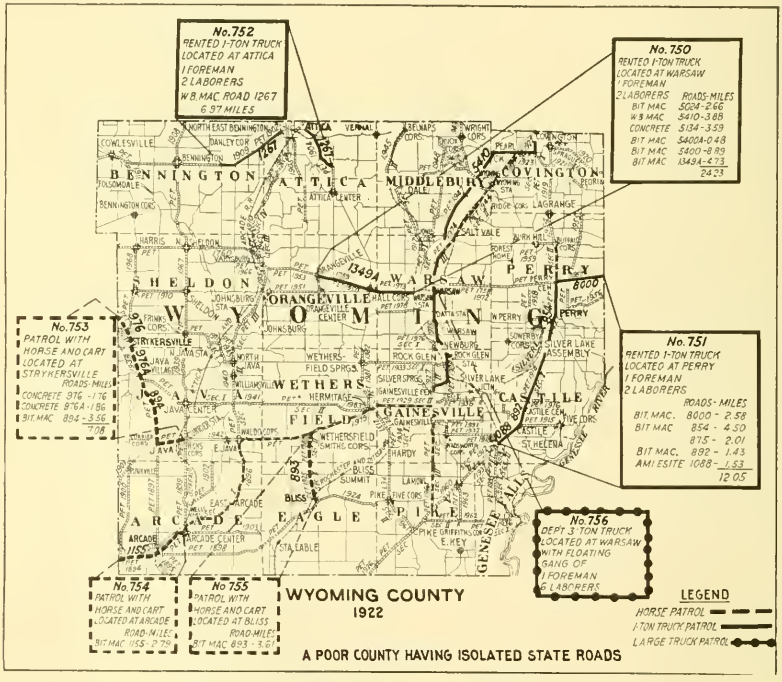
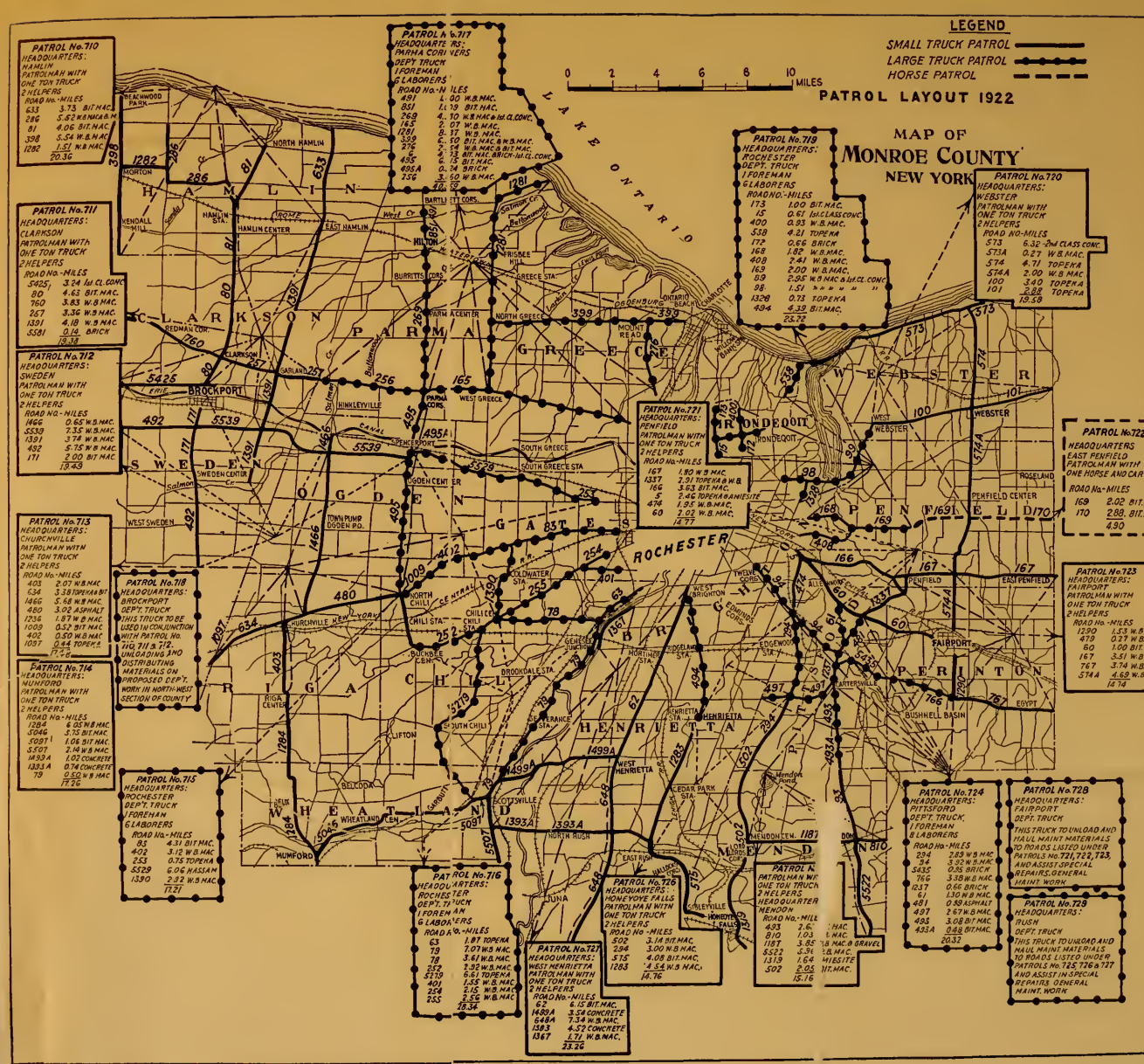


Fig. 157.—Maintenance patrol layout.

and keep shoulders, ditches, guard rail, culverts etc. in shape. On Division 7, this type of patrol takes care of 530 miles out of the total of 860 miles. On macadam roads, the equipment consists of 1-ton truck, shovels, picks, mattocks, push brooms, rakes, tampers, asphalt pouring pots, axe, scythes, straight edge. These small tools are supplemented from the general division equipment by small asphalt-heating kettle; and 1 bag batch concrete mixer for cold patch work as required.

Where patrols of this kind work entirely on rigid pavement roads, the force of men is generally reduced to 2. For work of this kind, the equipment shown in Fig. 158*B* is satisfactory.


LEGEND
SMALL TRUCK PATROL
LARGE TRUCK PATROL
HORSE PATROL
0 2 4 6 8 10 MILES
PATROL LAYOUT 1922
MAP OF
MONROE COUNTY
NEW YORK
LAKE ONTARIO
PATROL No.710
HEADQUARTERS:
HAMLIN
PATROLMAN WITH
ONE TON TRUCK
2 HELPERS
ROAD No.- MILES
633 3.73 BIT. MAC.
286 5.82 KANCA & M.
81 4.06 BIT. MAC.
398 5.54 W.B.M.AC
1282 1.51 W.B. MAC
20.36
PATROL No.711
HEADQUARTERS:
CLARKSON
PATROLMAN WITH
ONE TON TRUCK
2 HELPERS
ROAD No.- MILES
5425, 3.24 Ist CL. CONC
80 4.53 BIT. MAC.
760 3.83 W.B MAC.
257 3.36 W.B MAC.
1391 4.18 W.B MAC
5581 0.14 BRICK
19.32
PATROL No.712
HEADQUARTERS:
SWEDEN
PATROLMAN WITH
ONE TON TRUCK
2 HELPERS
ROAD No.- MILES
1466 0.65 W.B.MAC.
5539 7.35 W.B.MAC.
1391 3.74 W.B.MAC.
492 5.75 W.B MAC
171 2.00 BIT MAC
19.49
PATROL No.713
HEADQUARTERS:
CHURCHVILLE
PATROLMAN WITH
ONE TON TRUCK
2 HELPERS
ROAD No.- MILES
403 2.07 W.B.MAC
634 3.38 TOPEKA & BIT
1466 5.68 W.B MAC
480 3.02 ASPHALT
1236 1.87 W.B MAC
1009 0.52 BIT MAC
402 0.50 W.B MAC
1007 0.44 TOPEKA
17.76
PATROL No.714
HEADQUARTERS:
MUMFORD
PATROLMAN WITH
ONE TON TRUCK
2 HELPERS
ROAD No.- MILES
1284 6.05 W.B MAC
5046 3.75 BIT. MAC
5091 1.06 BIT MAC.
5507 2.14 W.B MAC
1393 A 1.02 CONCRETE
1393 A 0.74 CONCRETE
79 0.50 W.B MAC
17.26
PATROL No.715
HEADQUARTERS:
ROCHESTER
DEPT. TRUCK
1 FOREMAN
6 LABORERS
ROAD No.- MILES
85 4.31 BIT MAC
402 3.12 W.B MAC
253 0.75 TOPEKA
5529 6.06 NASSAU
1390 2.32 W.B MAC
17.21
PATROL No.716
HEADQUARTERS:
ROCHESTER
DEPT. TRUCK
1 FOREMAN
6 LABORERS
ROAD No.- MILES
63 1.87 TOPEKA
79 7.07 W.B MAC
78 3.61 W.B MAC
552 3.32 W.B MAC
5739 6.61 TOPEKA
401 1.55 W.B MAC
254 2.15 W.B MAC
255 2.56 W.B MAC
30.34
PATROL No.717
HEADQUARTERS:
PARMA CORNERS
DEPT. TRUCK
1 FOREMAN
6 LABORERS
ROAD No.- MILES
491 1.00 W.B.MAC.
851 1.19 BIT MAC.
269 4.10 W.B MAC & Ist CL CONC.
165 2.07 W.B MAC.
1291 8.17 W.B MAC.
399 6.50 BIT. MAC & W.B MAC.
276 7.54 W.B MAC & BIT MAC.
425 6.73 BIT. MAC. BRICK-Ist CL. CONC.
495A 6.15 BIT MAC.
256 0.34 BRICK
3.60 W.B MAC
40.62
PATROL No.718
HEADQUARTERS:
BROCKPORT
DEPT. TRUCK
THIS TRUCK TO BE
USED IN CONJUNCTION
WITH PATROL No.
719, 717 & 712.
UNLOADING AND
DISTRIBUTING
MATERIALS ON
PROPOSED DEPT.
WORK IN NORTH WEST
SECTION OF COUNTY
PATROL No.719
HEADQUARTERS:
ROCHESTER
DEPT. TRUCK
1 FOREMAN
6 LABORERS
ROAD No.- MILES
173 1.00 BIT. MAC.
15 0.61 Ist CLASS CONC.
400 0.93 W.B. MAC.
538 4.21 TOPEKA
172 0.66 BRICK
168 1.82 W.B. MAC.
408 2.41 W.B. MAC.
169 2.00 W.B. MAC.
89 2.85 W.B MAC & Ist. CL. CONC.
98 1.51 " " " "
1328 0.73 TOPEKA
494 4.39 BIT. MAC.
23.72
PATROL No.720
HEADQUARTERS:
WEBSTER
PATROLMAN WITH
ONE TON TRUCK
2 HELPERS
ROAD NO.- MILES
573 6.32 - 2nd CLASS CONC.
573A 0.27 W.B MAC.
574 4.71 TOPEKA
574A 2.00 W.B MAC
100 3.40 TOPEKA
101 2.81 TOPEKA
19.59
PATROL No.721
HEADQUARTERS:
PENFIELD
PATROLMAN WITH
ONE TON TRUCK
2 HELPERS
ROAD No.- MILES
167 1.90 W.B MAC.
1337 2.31 TOPEKA & W.B.
166 3.63 BIT. MAC.
5 2.46 TOPEKA & AMIESITE
474 1.95 W.B. MAC.
60 2.02 W.B. MAC.
14.77
PATROL No.722
HEADQUARTERS:
EAST PENFIELD
PATROLMAN WITH
ONE HORSE AND CART.
ROAD No.- MILES
169 2.02 BIT. MAC.
170 2.88 BIT. MAC
4.90
PATROL No.723
HEADQUARTERS:
FAIRPORT
PATROLMAN WITH
ONE TON TRUCK
2 HELPERS
ROAD No.- MILES
1290 1.53 W.B MAC.
479 0.27 W.B MAC.
60 1.00 BIT MAC.
167 3.51 W.B MAC
767 3.74 W.B MAC.
574A 4.69 W.B MAC
14.74
PATROL No.724
HEADQUARTERS:
PITTSFORD
DEPT. TRUCK.
1 FOREMAN
8 LABORERS
ROAD No.- MILES
294 2.89 W.B MAC
94 3.32 W.B MAC
5435 0.35 BRICK
766 3.38 W.B MAC
1237 0.66 BRICK
61 1.30 W.B MAC
481 0.88 ASPHALT
497 2.67 W.B MAC
493 3.08 BIT MAC
493A 0.48 BIT MAC
20.32
PATROL No.726
HEADQUARTERS:
HONEOYE FALLS
PATROLMAN WITH
ONE TON TRUCK
2 HELPERS
ROAD No.- MILES
502 3.14 BIT MAC.
294 3.00 W.B MAC.
515 4.08 BIT MAC.
1283 4.54 W.B MAC.
14.76
PATROL No.727
HEADQUARTERS:
WEST HENRIETTA
PATROLMAN WITH
ONE TON TRUCK
2 HELPERS
ROAD No.- MILES
62 6.15 BIT MAC.
1499A 3.24 CONCRETE
648A 7.34 W.B MAC.
1393 4.52 CONCRETE
1367 1.71 W.B MAC.
23.36
PATROL No.728
HEADQUARTERS:
FAIRPORT
DEPT. TRUCK
THIS TRUCK TO UNLOAD AND
HAUL MAINT MATERIALS
TO ROADS LISTED UNDER
PATROLS No. 721, 722, 723,
AND ASSIST SPECIAL
REPAIRS, GENERAL
MAINT. WORK
PATROL No.729
HEADQUARTERS:
RUSH
DEPT. TRUCK
THIS TRUCK TO UNLOAD AND
HAUL MAINT. MATERIALS
TO ROADS LISTED UNDER
PATROLS No. 725, 726 & 727
AND ASSIST IN SPECIAL
REPAIRS, GENERAL
MAINT. WORK
HAMLIN
CLARKSON
PARMA
GREECE
WEBSTER
PENFIELD
PERINTON
ROCHESTER
HENRIETTA
RIGA
CHILI
GATES
OGDEN
SWEDEN
WHEATLAND
MENDON
IRONDEQUOIT
BROCKPORT
NORTH HAMLIN
HAMLIN CENTER
EAST HAMLIN
HILTON
PARMA CENTER
NORTH GREECE
WEST GREECE
SOUTH GREECE
WEBSTER
PENFIELD CENTER
EAST PENFIELD
FAIRPORT
EGYPT
BUSHNELL BASIN
WEST BRIGHTON
PENFIELD
CHURCHVILLE
CHILI STA.
CHILI CENTER
NORTH CHILI
WEST HENRIETTA
SOUTH CHILI
LIFTON
MUMFORD
SCOTTSVILLE
NORTH RUSH
EAST RUSH
LUNA
MENDON CEN.
MENDON
HONEOYE FALLS
LIMA
GENESEE JUNCTION
EDGEWOOD STA.
CEDAR PARK STA.
CLARISSA
BARTLETT CORS.
BURRITTS CORS.
GARLAND
REDMAN COR.
SWEDEN CENTER
OGDEN CENTER
TOWN PUMP
OGDEN PO.
KENDALL MILLS
MORTON
BEACHWOOD PARK
MOUNT READ
FRISBEE HILL
GREECE STA.
OSBURN BEACH
CHARLOTTE
LAKE ONTARIO
Buttonwood Cr.
Salmon Cr.
Spencerport
Canal
Erie
Genesee R.
Honeoye Cr.
Mendon Pond
Allens Creek
Irondequoit Bay
Genesee Junction R.R.
Rochester Junction & Terminal R.R.
Rochester & Pittsford R.R.
Lehigh Valley R.R.
New York Central R.R.
Erie R.R.
Rochester & Eastern R.R.
Rochester & Southern R.R.
Rochester & Lake Ontario R.R.
Rochester & Syracuse R.R.
Rochester & Eastern Rapid R.R.
Rochester & Sodus Bay R.R.
Rochester & Lake Ontario Water Line R.R.
Rochester & Lake Ontario Water Line R.R.
Rochester & Lake Ontario Water Line

eating kettle;
equired.
ent roads, the
ind, the equip-

ment shown in Fig. 158*B* is satisfactory.

(*c*) *Three-ton Truck and Gang of* 6 *to* 12 *Men.*—This organization unit is a recent development and serves very effectively for work on roads requiring a large amount of surface patching, small areas of complete reconstruction or extensive surface oiling. Gangs of this nature do all work not sufficiently important to warrant formal contract awards. They are as a rule responsible for the direct maintenance work on from 17 to 40 miles of road (see Figs. 157 and 157*A*) and in addition deliver materials,

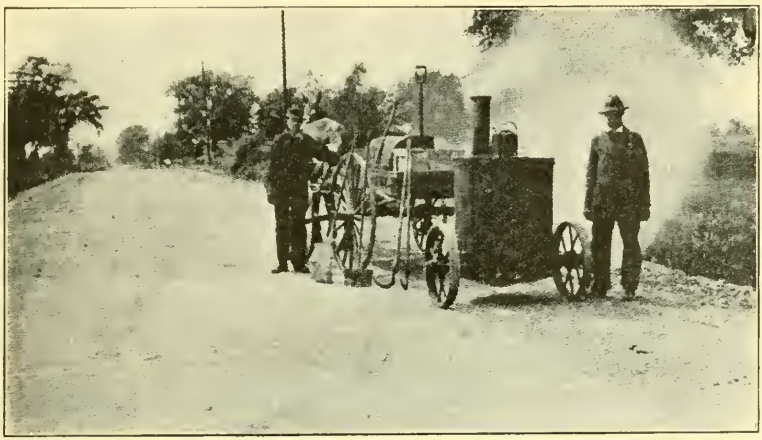


FIG. 158*A*.—Horse patrol (State of Illinois). Equipped for repairing concrete pavements.

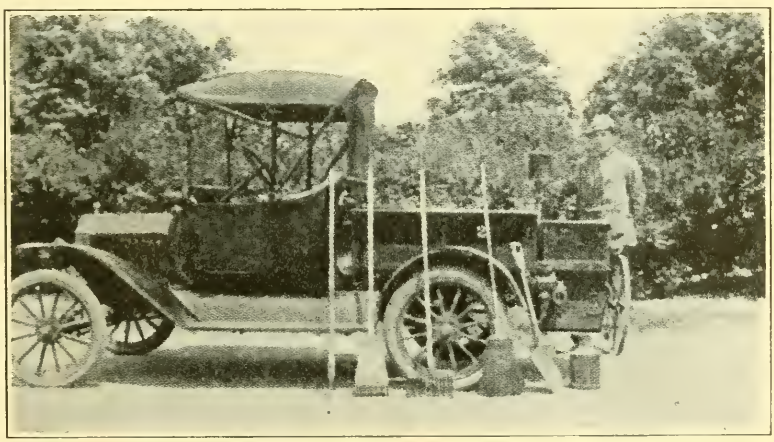


FIG. 158*B*.—Small truck patrol equipped for rigid pavement repair.

reconstruct weak areas and handle surface oiling. In Division 7 (used as illustration) sixteen gangs of this nature handled the maintenance on 300 miles and in addition they reconstructed in 1922 approximately 4.3 miles of road and handled all the surface oiling treatment on the division.

The equipment required other than the small tools previously listed for patrol is

Roller Oil distributor Scrapers Tractors Any special machinery desired	Division Equipment List, page 427.

(*d*) *Contract Work.*—Extensive reconstruction and oiling are usually handled by contract awards but oiling is gradually being taken over by these gangs as they do better work, cheaper than the contract method.

Large Equipment.—The best number and the kind of large machinery required will vary for each district. The following list, Division 7, gives an idea of the units found useful for a territory of this general character. A storehouse with repair and overhauling equipment is necessary.

Storehouse Organization (*Division* 7).—A workshop equipped with travelling hoists, electric drills, grinders, lathes, milling machine, drill presses and small tools to enable mechanics properly to take down, overhaul, repair and reassemble trucks and other equipment. Floor space of workshop should be large enough to place six or eight trucks at a time on the floor, say 40 × 80 or 50 × 100 ft.

In addition, there should be shed room enough to house all trucks during winter and equipment brought in for storage or overhauling, also, a stockroom for small tools.

Mechanics at storehouse—one foreman mechanic in charge of storehouse and all equipment whether at storehouse or working on roads. Should have a small truck in order to make inspection and repairs to plant in field. Also, a helper to be at storehouse at all times. In winter months to overhaul trucks and plant properly, there should be in addition at storehouse seven or eight mechanics. These latter could be the best of the truck drivers used in the summer on the road work.

Large Machinery Equipment (Division 7)

10-ton rollers	7
5-ton caterpillar tractors	1
Steam scarifiers to attach to 10-ton rollers	2
Large blade scrapers (Austin Rip Snorter)	1
4,000 lb. 10-ft. blade scraper	7
3-ton trucks	20 supplemented by a few additional rented trucks. 3 equipped with 800-gal. cold oil distributors.
¾-ton speed trucks	4
1-ton Ford trucks rented with patrolman	30
Asphalt distributors for penetration work with roller	3
Portable belt conveyor unloaders	7
Street sweepers (rotary, horse drawn)	7

Small 1-bag batch concrete mixers (cold patch)..... 15
Small concrete paving mixers (3-bag batch)..... 2
Necessary side forms and small tools
Portable asphalt-heating kettles
300 gal..... 10
150 gal..... 12

For this Division, quarrying and crushing equipment is not needed as commercial stone can be obtained readily at a reasonable rate.

Materials and Methods.—The general principle of pavement maintenance is to prevent noticeable wear rather than to neglect minor flaws and then repair serious damage. Patch any hole large or small as soon as it appears, "Catch them young and treat them rough." Effective maintenance increases the life of pavements, increases traffic comfort and reduces the cost of traffic operation. It is the best possible investment for the community and is essential to the success of any highway program. Maintenance includes the upkeep of ditches, shoulders, culverts, guard rails, guide signs and pavement repair; the fundamental principle of pavement work is to repair *like with like.* That is, a hole in an earth road should be repaired with earth, gravel with gravel, macadam with macadam, amiesite with amiesite, Topeka with Topeka, brick with brick etc. This seems perfectly obvious but it is violated with clockwork regularity and the result is a patch that looks badly, wears badly, rides badly and costs like the devil; it is a great temptation to use any easily manipulated patching material as a cure-all like David Harum's cure for spavin, ringbone, pips in hens, etc., but it is poor policy. The following discussion outlines briefly the materials and methods in ordinary well-balanced practice.

Incidental Maintenance.—Shoulder maintenance consists in cutting weeds and grass either with farm mower or hand tools; maintaining the elevation and shape of the earth by means of blade scrapers hauled with trucks, roller or tractors (see Fig. 164), drags or hand-tool methods or the addition of stone, gravel, etc. bound with bitumen on the main-travelled roads. The cost of this work has a wide range depending on the excellence of the maintenance and on the width of pavement and volume of traffic; for pavements having the widths recommended, page 70, and where the maintenance is fairly effective, a fair set of costs is about as follows:

	Per Year
Class I traffic (18-ft. pavements).....	$200 to $400 per mile
Class II and III traffic (16-ft. pavements).....	100 to 200 per mile
Class IV traffic (12-ft. pavements).....	100 per mile

Ditch cleaning is largely a hand-tool proposition supplemented in some cases by blade scraper work.

Guard rail, signs etc. are routine mechanical operations.

This incidental work is about the same for all types of pavement.

Macadam Pavements.—Macadam pavement maintenance involves repair of small areas of structural weakness such as frost boils, etc., the repair of pot holes in the surface due to ravelling of the top course and the care of minor surface irregularities and roughness due to traffic wear.

Frost Boils.—Weak areas are dug up and replaced by new pavement of adequate depth reinforced by underdrains if necessary; this work follows the principles of depth design and construction methods described under Macadam Design and Construction, pages 191 to 249. For a well-designed pavement, this kind of work rarely exceeds over $\frac{3}{10}$ of 1 per cent of the area per year. In 1917 in New York State 82 miles out of a total of 5,600 miles broke through or $1\frac{1}{2}$ per cent of the area. These breaks occurred largely on the old thin roads totalling 2,000 miles or a percentage of 4.2 per cent for these old weak pavements. For well-designed macadam pavements, the item of frost boil repair should not exceed $50 per mile per year. Work of this kind is done by the large Gang Organization Unit previously described.

Repair of Pot Holes.—Pot holes due to ravel of the surface and not to structural weakness are of two classes. Incipient depressions less than $\frac{1}{2}$ in. deep and well-defined holes.

The first class of surface defect is remedied by sweeping out the hole, painting it with a thin coat of maintenance bitumen (Cold Patch Fluid) by means of pouring pot and broom adding dustless stone or slag screenings and tamping thoroughly. Screenings containing sharp flint or other hard material should not be permitted on account of tire damage.

Well-defined holes are repaired by cutting out the edges of the hole to a square edge, painting the edge and bottom with cold patch liquid and filling the hole with a cold patch mixture of bitumen, stone and sand or stone and screenings. For depression of about 1-in. depth $\frac{3}{4}$-in. stone is used. Holes deeper than 1 in. are dug out to the full depth of the top course; squared up and filled with regular sized top stone ($1\frac{1}{2}$ to $2\frac{1}{2}$ in.) rolled with a 10-ton roller. Some engineers advocate light rolling but our experience indicates that the stone should be hard rolled but not crushed. Hot binder grade bitumen is then poured as for penetration macadam and filled with screenings. The patch is rolled lightly at once and thoroughly the next morning after the bitumen has hardened a little. A seal coat can be added but is rarely necessary as patching of holes is generally preliminary to extensive surface oiling. Work of this kind is done by the regular patrol gang. The amount of material required has a wide range for different roads.

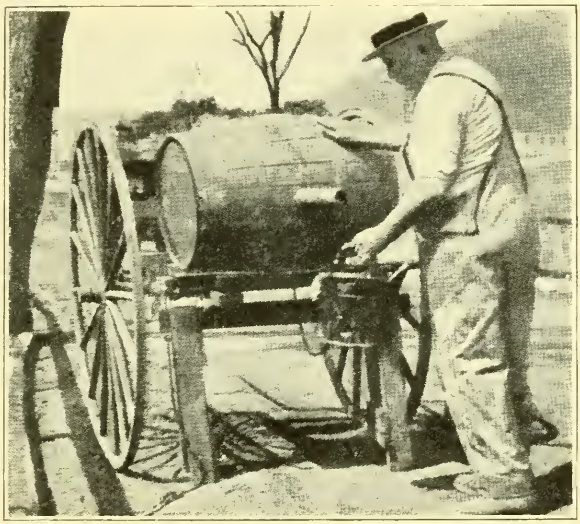
In 1922, patching holes of this kind on Division 7 required from 10 to 60 tons of stone or slag per mile (50 per cent $\frac{3}{4}$-in. and 50 per cent screenings) and from 200 to 1,200 gal. of some kind of bitumen per mile. Cost of this work is difficult to segregate but is probably about $150 to $200 per

mile average on waterbound and about $50 to $100 per mile on bituminous macadam under Class II and III traffic.

Cold patch bituminous compounds are a comparatively recent development. There are a number of satisfactory materials on the market, the best known being some form of

1. Asphaltic emulsion.
2. Tar cut back.
3. Asphalt cut back.

Good results can be obtained with all these materials. Locally, the best results have been obtained with the asphaltic emulsion but it is the



Handy rig for patrolman to transport bituminous patching material.

most expensive and will not keep over winter. The tar cut back is better for early spring use as it flows better at cool temperatures and is not damaged by winter storage. The cut back cold patch mixture requires from 15 to 20 gal. of standard fluid per cubic yard of mixed stone and sand or stone and screenings. Asphalt emulsion requires a little more about 0.9 gal. per cubic foot of stone. The manipulation of this material is well described in the following quotation from the Barrett Company's "Vest Pocket Handbook." Maintenance men say that the greatest difficulty they experience in connection with the use of this material is the tendency on the part of the patrolman to use too much fluid as the mixture is easier to prepare under such treatment. *Don't use too much bitumen as it produces a patch which tends to creep and shove under traffic action.*

MANIPULATION OF TARVIA-KP

Tarvia-KP is a material that can be used for patching at any time of the year. It is as serviceable in winter as it is in summer.

Intelligent use keeps bituminous macadam and other bituminous pavements in perfect condition all the time. Holes in wood block, brick and stone block may be successfully patched with it.

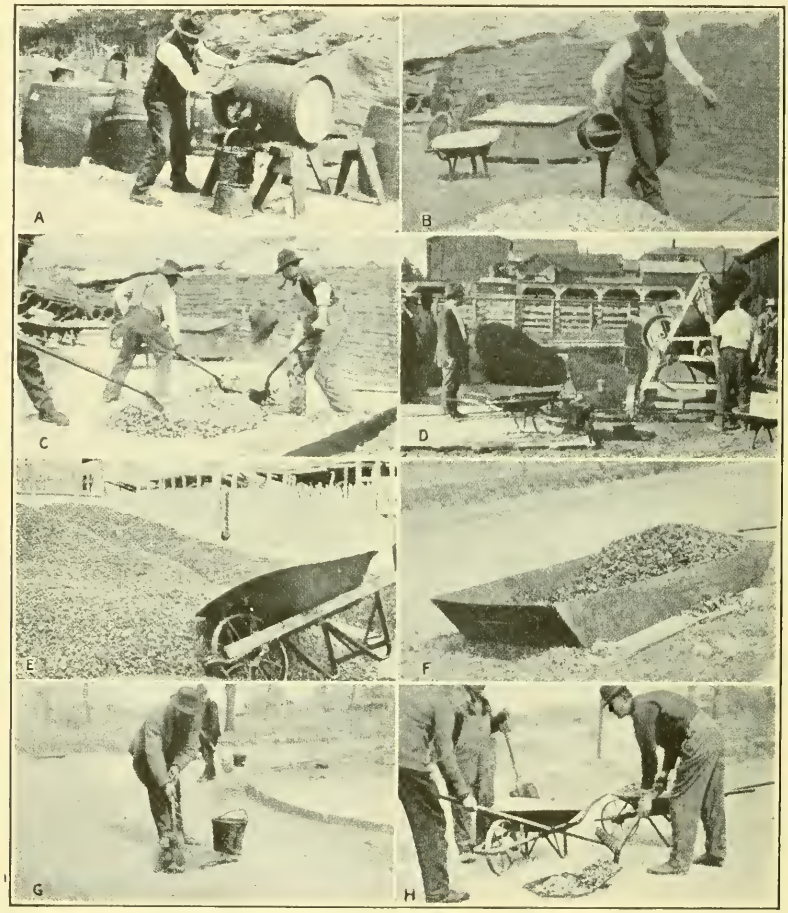


FIG. 159*A*.

A, *B*, *C* and *D*, mixing by hand and machine. *E*, *F*, storing. *G*, preparing hole for patch. *H*, spreading and compacting.

Tarvia-KP is used cold. It is used at any time, in any place. A batch of the mix may be made today, and need not be used until it is required, weeks hence. Batches may be made on rainy days and stored away for use later on, thus keeping the repair-gang busy, rain or shine.

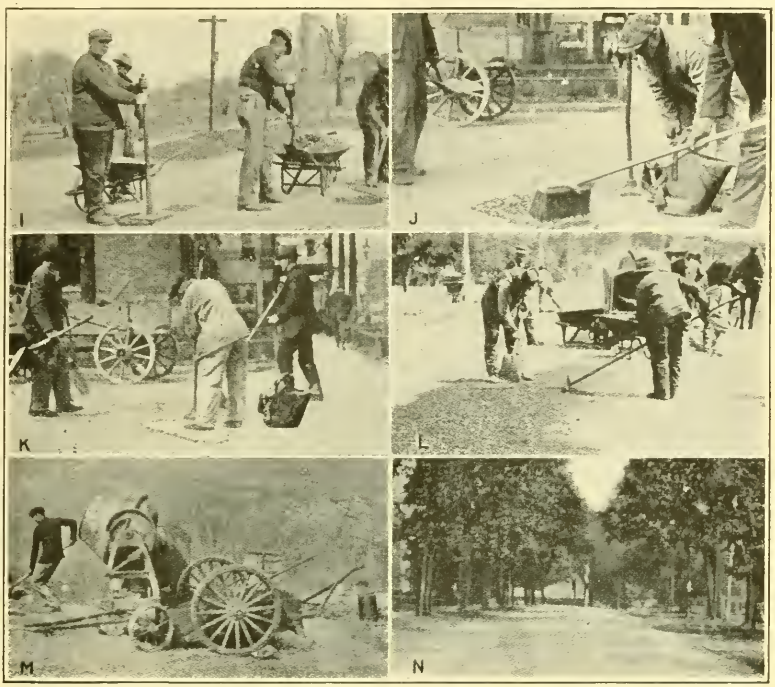
HOLES AND HOW TO PATCH THEM

Usually, holes are of one of two kinds: They either are breaks in the skin-surface of the road, or they are deep depressions. The breaks can usually be mended by carefully sweeping them out and proceeding as is described below under the penetration method; the deep depressions repaired by either the mixed method or the penetration method.

Deep Depressions. Mixed Method

No hard and fast rule for proportioning the ingredients of the mix can be given, as sands and stone vary greatly in quality; but, in general, the following will be found to work satisfactorily:

One cubic yard of a mixture of 1 part sand and 3 parts of ¾-in. stone. (Stone held on ½-in. screen and passing 1¼-in. screen.) Sixteen to eighteen gallons of Tarvia-KP.



(*Courtesy of the Barrett Co.*).

Fig. 159*B*.—Manipulation of cold patch. (KP).

I, *J*, *K* and *L*, spreading and compacting.
N, a well kept macadam pavement in a residential street.

These may be mixed by hand, using shovels and turning the mix about seven times, or they may be mixed in a concrete mixer of the batch type. A full minute is required to mix the materials in a mixer.

After the mix has been made, it may be either used immediately on the road or it may be stored away for future use, covering it over with a tarpaulin or other suitable shield to keep the rain out. While the mix is set away it is curing. A hard crust will form on the outside, but this will in no way injure the bulk. The mix will be found to be in perfect condition 6 weeks, and even longer, after mixing. A pickax will loosen the tarred stone so that it may be shoveled into a cart or wheelbarrow and taken to the point of application.

Filling Holes

Cut the sides of the hole vertically, and clean out the old material thoroughly. If the hole is over an inch in depth, fill to within 1 in. of the top with clean broken stone, and tamp. The larger the stone up to 2½ in. that can be used for this work, the better. In other words, the stone is to furnish a firm foundation for the patch. The stone should be

thoroughly rammed. Then paint the hole to be patched with a light coat of Tarvia-KP (from ¼ to ½ gal. to the square yard), and deposit the mix therein. Place a quantity sufficient to a little more than fill the hole flush with the surface, and then tamp with a heavy iron tamper, or roll with a road-roller until the surface of the patch is level with the surrounding surface of the pavement. Apply a light seal-coat of Tarvia-KP, cover with screenings, and the patch is ready for traffic.

A dish-shaped shallow hole may be patched the same way, or by the penetration method.

Great care must be taken to see that not too much Tarvia-KP is used. Use too little rather than too much. Too much acts as a lubricant for a time and tends to make the patch creep out of the hole.

It does not matter how large or how small the patch is, Tarvia-KP will mend it.

Penetration Method

Instead of mixing the ingredients, a penetration-method patch may be made. Owing to the fluidity of Tarvia-KP the method is not usually so good as the mixed method except for very small holes. The hole is cleaned out, a paint coat of the liquid about ½ gal. to the square yard is spread over the bottom, and 3-in. stone is deposited so that the hole is slightly more than filled. Tarvia-KP is then poured over the stone, using for each square yard about ½ gal. for each inch in depth of stone. The patch is covered with screenings and thoroughly tamped with a heavy iron tamper. A light seal-coat about ½ gal. per square yard, is then spread over the patch and it is allowed several days in which to set up before traffic is admitted, although this is not absolutely necessary.

PATCHING SHEET ASPHALT[1]

The old sheet asphalt and binder should be removed and the hole cleaned out. Paint the bottom of the hole with a light coat of Tarvia-KP. Place the mix, roll, spread the seal-coat of Tarvia-KP. Place the mix, roll, spread the seal-coat, and use screenings as before. The mix should be made as follows:

One part sand, three parts stone, varying in size and grading of stone to suit the hole to be patched and the local stone conditions. The mix should be so proportioned that it will tamp solid. No excess sand should be used or a rolling-patch will develop. Sixteen to eighteen gallons of Tarvia-KP to the cubic yard is the usual requirement.

MISCELLANEOUS PATCHING[1]

Concrete Pavements.—Holes in brick and cement pavements may be patched in the manner already described. Cracks in these pavements may be repaired by first cleaning them out thoroughly, and then filling them with a mastic made of Tarvia-KP and fine sand, using a slight deficiency of sand so that the liquid may find entrance into the crack or joint, and yet not thin enough to flow away easily.

Wood Block Pavements.—It sometimes happens that a hole develops in a wood-block pavement, and that there are no blocks available to patch with. A Tarvia-KP patch, made the same as for bituminous macadam, will serve well until such time as a wood block patch can be substituted.

BRIDGE FLOORS

The wear and tear on plank floors on bridges is considerable and has led a number of county engineers and others to take up the planks and substitute a concrete floor. This is always a dangerous change to make, for the bridges are not usually designed for the increased dead load of a concrete floor. A safer and better plan is to put a

[1] For temporary relief only.

Tarvia-KP top over the plank floor. This will add comparatively little weight and will provide an excellent roadway. The method of construction is as follows:

Sweep the planks thoroughly and when they are dry apply a light paint-coat of Tarvia-KP, about ¼ gal. to the square yard. Place a 2-in. mixed top made of ¾-in. stone, sand and the liquid in the proportions given under "Holes and How to Patch Them." This may be placed to have a depth of 2½ in. at the center and 1 in. at the sides, when rolled. Roll or tamp well, give a ⅓-gal. seal-coat of the liquid and cover with screenings or sand.

RESURFACING OLD MACADAM WITH TARVIA-KP MIX[1]

Usually the old macadam is scarified and reshaped with the addition of new stone if necessary. If, however, the surface is in general in good condition, the ruts and depressions are repaired with a mix of crushed stone and Tarvia-KP. The road is then swept and a paint-coat of the liquid is applied to the entire road-surface. On this a mix of sand, broken stone, and Tarvia-KP is spread to a depth of 2½ in. and rolled. When the rolling is completed, a seal-coat of Tarvia-KP is applied and the new top is covered with pea-gravel or stone-chips. The road is allowed to set up for several days before traffic is turned onto it.

The mix is made in a concrete mixer. For a small mixer a good proportion has been found to be 1 cu. ft. of sand, 4 cu. ft. of stone, and 3 gal. of Tarvia-KP. These are mixed for one full minute at least, and are then dumped in a pile to cure for a week. At the close of the day's work, a quart of kerosene and two shovelfuls of stone are revolved in the mixer to clean it out.

If the mix shows a tendency to wave under the roller to any great extent, let it cure for a day or so. The volatile oils will evaporate, leaving the mix stiffer and firmer.

Tarvia-KP is supplied in barrels. It can be stored without deterioration indefinitely, even in winter weather. It is well, however, to stir the contents before using. The barrels hold approximately 50 gal. Where there are facilities for storing the liquid in bulk, it may be supplied in tank-cars. The storage-tank should be supplied with coils or other means for heating the liquid in cold weather. Tank-cars hold from 8,000 to 10,000 gal. Tarvia-KP should never be heated in open tanks or kettles. It can never be mixed with very hot stone or sand.

Use Tarvia-KP sparingly. You can always add, but you cannot subtract.

Calcium Chloride Treatment.—The use of calcium chloride as a temporary maintenance method for the first season on waterbound roads is explained on page 205.

Surface Oiling.—Surface oiling produces the final smooth, dustless surface demanded by modern traffic. It is the final stage of macadam maintenance. All structural defects and surface holes must be repaired before surface oiling is done. There are three well-defined conditions in connection with this work which require different methods of treatment.

1. Light oiling to liven up a comparatively smooth surface.
2. Medium treatment to smooth and seal a rough surface.
3. Heavy hot oiling with thick cover mat to repair temporarily a road in very poor condition.

The light type of treatment is used where the surface texture of the pavement is similar to Fig. 85, page 217. That is, the surface is smooth but requires some bitumen to liven up the binder on penetration bituminous macadams. For a treatment of this kind, 0.2 to 0.25 gal. of bitu-

[1] Resurfacing with cold patch is rarely desirable.

men is applied after the road is swept clean of dust and loose material of all kinds. The oil is applied by mechanical distributors (Fig. 160) one-half of the road being treated at a time to avoid inconvenience to traffic. The

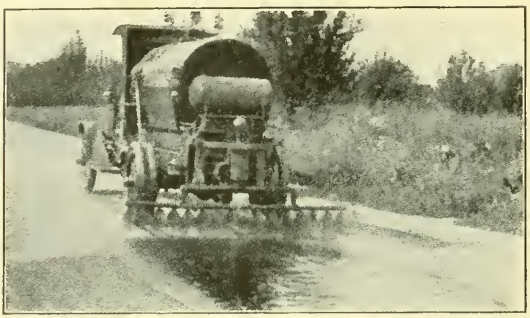


FIG. 160.—Handy sized truck for maintenance surface oiling.

oil is immediately covered with a light coat of clean sharp sand, dustless stone or slag screenings using about 18 to 30 tons of cover per mile of 16-ft. road. The road surface must be clean when the oil is applied but

FIG. 161.—16-ft. Old Tarvia penetration bituminous macadam rough but firm and free from holes (Class IIA traffic).

This road was successfully treated by the application of 0.3 gallons per sq. yd. T. C. A. New York State specifications (page 442) covered with 100 tons per mile slag dustless screenings rolled thoroughly with 10-ton roller.

slight dampness does no harm so long as water is not standing in pools. Either a light cold tar or light asphaltic oil can be successfully used. Locally, we prefer the tar for treating waterbound macadam or tar penetration macadams and prefer the light asphaltic oil for treating

asphalt penetration macadam, see specifications, Items 68 and 73, page 439 and 442. Sharp sand makes the best cover material as it is less likely to cause excessive tire wear.

The medium type of treatment is used where the surface is rough as shown in Fig. 161.

The manipulation is the same as for the light treatment except that a little more oil is used from 0.3 to 0.4 gal. per square yard and more cover 80 to 100 tons per mile of 16-ft. road. Three-fourth-inch stone rolled until they are completely crushed may be used for cover but the dustless screening cover rolled in is better practice.

The heavy hot oil treatment is used sparingly as when a road gets into the condition where this method is needed, it is generally better policy to do a good job of resurfacing. This method is used as a stop gap to save a road where the funds are insufficient for a new top course. From 0.6 to 0.7 gal. per square yard of binder grade bitumen (either tar or asphalt) is applied hot to the well-cleaned surface and covered with from 100 to 130 tons per mile (16-ft. road) of a mixture of about 75 per cent ¾-stone and 25 per cent dustless screenings. This cover is rolled hard until all the ¾-in. stone are crushed down to the screening size. The cost of this treatment ranges from $1,200 to $1,600 per mile of 16-ft. road (1922 cost conditions).

Surface oiling of either the light or medium method is routine procedure in macadam maintenance. It starts the second season on waterbound roads and continues at irregular intervals throughout the life of the surface. It costs on the average about $350 to $450 per mile for each oiling which amounts to about $300 per mile per year average under Class II traffic for the waterbound type. On penetration bituminous macadam roads, it starts the second season on tar penetration and the third or fourth season on asphalt penetration and continues at irregular intervals as required. It costs about $350 to $450 per mile for each oiling which amounts to about $150 to $200 per mile per year average under Class II traffic. All costs are 1922 cost conditions.

The following tabulation gives a rough idea of the relation of the different items of maintenance to total yearly cost for 16-ft. macadam roads well-designed and reasonably well-maintained.

Class of work	Bituminous macadam Class II traffic, cost per mile	Waterbound macadam Class III traffic, cost per mile
Repair of weak areas	$50	$50
Surface patching	50 to 100	150 to 200
Surface oiling	150 to 200	200 to 300
Shoulders, ditches, etc	150	100
Totals	$400 to $500	$500 to $650

NOTE.—Each of these items includes an allowance of 10 per cent for administrative overhead and equipment.

The following quotation from the Report of Fred Sarr, former Maintenance Deputy of New York State, reinforces the data given.

Efficient maintenance of macadam pavements, particularly of the waterbound type, of which there are 2,535 miles in the State system of improved highways, necessitates frequent surface treatments with bituminous materials or constant patching of the holes that rapidly develop under the present day motor vehicle traffic.

Frequent surface treatments are objectionable not only from a traffic standpoint, but from the fact that such treatments tend to build up an unstable mat of bituminous material and mineral aggregate on the surface of the pavement that is displaced by the fast-moving motor vehicle traffic, and develops a rough and uneven surface.

It has, accordingly, been the policy of this Bureau to restrict the use of surface treatments and wear the surface mat down as this is possible before giving another general surface treatment.

This method, while tending to provide a smoother surface, requires constant patching during the later stages of the wearing down process.

Much time and thought have been given to the study of the results obtained by various methods of manipulation and materials used in patching macadam surfaces.

In making these patches to pavements carrying any considerable amount of motor vehicle traffic, it is necessary to bind the mineral aggregate with some form of bituminous material.

Light asphaltic oils and refined tar products, similar to those used for surface treatments, have been used extensively for light, thin patches, painting the area to be patched with the bituminous material and covering with stone chips or sand.

Heavy binders that require heating have been used in the same manner.

The most satisfactory results have been obtained, where the required patch must be ½ in. or more in depth, by mixing the mineral aggregate with a heavy asphalt or tar binder, cut back with light voltaic oils to a consistency that will mix readily with the mineral aggregate when cold, also with an emulsified asphalt binder used in the same manner.

The bituminous material and stone aggregate, being mixed either by hand or in a small concrete mixer, permits of a proper proportioning of the materials which has been demonstrated to be about 6 per cent in weight of solid bitumen or mineral aggregate used, or about 1 gal. of the cut back or emulsion per cubic foot of crushed stone.

With asphalt cut back the best results have been obtained by using a material made from an asphalt binder, having a penetration of about 165, cut back with about 33 per cent in weight of naphtha.

With tar cut back the best results have been obtained with a material made from a refined tar binder having a melting point of about 60°C., cut back with about 40 per cent in weight of tar oils, of which at least 60 per cent shall distil up to 235°C.

A very satisfactory material for patching purposes is an emulsified asphalt containing about 65 per cent of asphalt binder having a penetration of about 165.

This material may be diluted with water if desired, and may be mixed with wet mineral aggregate when found in that condition. It readily separates from the emulsified state when combined with crushed stone in the so-called open mix.

The resultant adhesive qualities of an emulsified asphalt appear to be better than can be obtained by the same asphalt in any other form.

The only tangible reason advanced for this result is that the water in the emulsion may carry the binder into the pores of the material or pavement to which it is applied.

The patch made with emulsified asphalt hardens to a condition of stability much quicker than one made with cold oils or tars or cut back binder that we have used, and is, for this reason, preferable to those materials for patching work on heavy traffic highways.

Very good results have been obtained with the cut back tar cold patch material, particularly on medium to light traffic highways, where the patching material is not thrown about by traffic to any great extent.

In order to obtain efficient results in patching with a tar binder, it is necessary to make a so-called close mix, by using a graded mineral aggregate having a minimum amount of

voids, which, however, will not permit the volatile oils to evaporate as fast and the patch to become stable as quickly as may be obtained with asphalt emulsion when used in the open mix. It is, accordingly preferable when using tar, to mix same with the mineral aggregate and leave in shallow piles for about 2 days before applying to the road surface.

The necessity for using the close mix with tar binders, is due to the fact that tar products are more susceptible to the heat and cold than asphalts.

In other words, if starting with the two materials of the same consistency at 60°F. and the temperature is raised to that of a pavement on a hot summer day, say 130°F., the tar is much more fluid than the asphalt and tends to flow away from the open minimum aggregate, and the open patch will show a tendency to ravel. Again when the temperature is reduced to that of a pavement on a winter day, the tar becomes much more brittle than the asphalts and again the open patch with tar binder is much more liable to ravel out than one made with asphalt binder.

A comparison of the result obtained with the two materials each of which contains a quantity of the semi-volatile oils sufficient to permit them to be applied to the surface of the pavement at 60°F. as a surface treatment, demonstrates that the tar, by reason of its greater fluidity on a hot summer day, will penetrate the old pavement to a greater extent than the asphalts, and thereby serves more as a binder to the old pavement. It is for this reason that cold tars are generally used as the first and second treatment of a waterbound macadam pavement. Subsequent treatments of heavy asphaltic oils, carrying about 65 per cent of solid bitumen, will give more efficient and lasting results if used conservatively, that is, if the successive treatments do not follow each other too closely.

When successive treatments are given every year as a dust layer or to obviate the necessity for patching, cold tar is preferable in that it does not build up a mat on the surface of the pavement to the extent obtained with asphaltic oils.

Providing a mat is built up with successive tar treatments, the same will generally lie flat and not shove under traffic, and develop a wavy and corrugated surface as is often obtained with too frequent surface treatments with asphaltic oils.

This resulting difference is due to the aforesaid difference in consistency at summer temperatures of the pavements.

The tar being so fluid at summer temperature, it appears to retain a smooth surface by the effect of gravity, while the asphalt simply softens sufficiently to permit the surface mat to be displaced by traffic, which displacement increases from day to day and often necessitates the entire removal of the old mat.

Another factor to be considered in deciding upon the material to be used for the surface treatment is the condition of the old pavement.

Where the old macadam is composed largely of small particles of crushed rock and dust, and is in a more or less loosened condition, and is subject to displacement by traffic, a light asphaltic oil is preferable to cold tar for surface treatments. The asphaltic oil treatment develops into a mat or carpet over the macadam which remains more or less plastic, even at low temperatures, and displacement of the macadam under traffic does not result in the shattering and the ultimate destruction of the mat to the extent obtained under similar conditions with tar treatments.

Also for the same reason, asphaltic oils give the best results on pavements where steel-shod traffic predominates.

The best results obtained with tar treatments are where the old macadam pavement is clean or free from dust and where the pavement is firm and sound, and the stone fragments do not displace under traffic, and where motor vehicle traffic predominates, also where a minimum amount of cover material is used in conjunction with bituminous material.

Macadam pavements surface treated with tar are, however, much more slippery for horse traffic in cold weather than those treated with asphaltic oils.

In my report of a year ago, I discussed to some length the subject of the extensive breaking through of many of the pavements during the spring months.

Referring to such report it will be noted that the total area actually broken during the spring of 1916 was equivalent to 82 miles of pavement 16 ft. wide, and that the broken areas were distributed over many projects aggregating to a total of 1,939 miles, of which an average of 4.2 per cent was broken through.

During the season of 1916, about 75 per cent of the total broken areas were substantially repaired, and about 238 miles of the weaker pavements were resurfaced.

The spring of 1917 appeared to be a repetition of the previous year as to the amount of broken pavements.

The result of a survey to determine the extent of the broken pavements when tabulated indicates that the total broken areas were, however, but 60 per cent of the total of the previous year.

The total length of the various projects involved aggregating 2,090 miles about 9 per cent larger than those reported in the previous year. Of this total length the equivalent of about 48 miles of pavement 16 ft. wide was broken up or about 2½ per cent of the total length involved.

MATERIALS—NEW YORK SPECIFICATIONS

Item 64—Specification for Bituminous Material A Mixing Method (Type 1)

This material shall have the following characteristics:

1. It shall be free from water.
2. The various hydrocarbons composing it shall be present in a homogeneous solution.
3. It shall have a specific gravity at 77°F. of not less than 0.99.
4. It shall have a penetration (77°F., 100 g., 5 sec.) of not less than 70 nor more than 85.
5. It shall have an oven evaporation loss of less than 4 per cent. The penetration (77°F., 100 g., 5 sec.) of this residue shall be at least 50 per cent of the original penetration.
6. Its solubility at air temperature in carbon disulphide, for the following named products, shall be at least 99.5 per cent for pure bitumen products, 95 per cent for Bermudez products, 81 per cent for Cuban products and 66 per cent for Trinidad products.
7. The solubility of the bitumen, at air temperature, in 76°Be. paraffin petroleum naphtha distilling between 140° and 190°F. shall be between 68 and 88 per cent.
8. The bitumen shall show between 8 and 17 per cent fixed carbon.
9. It shall show an open flash point not less than 375°F.
10. It shall not contain more than 4.7 per cent paraffin scale.
11. It shall show a toughness at 32°F., not less than 10 cm. Toughness is determined by breaking a cylinder of the material 1¾ in. in diameter by 1¾ in. in height in a Page impact machine (A. S. T. M. 1908). The first drop of the hammer being from a height of 5 cm. and each succeeding blow increased by 5 cm.
12. It shall have a ductility at 77°F. of not less than 25 cm. (Dow mold).

All bituminous material A shall be sampled by an Engineer of the Department of Highways and samples sent to the Bureau of Tests, Albany, N. Y.

Item 65—Specification for Bituminous Material A Mixing Method (Type 2)(Topeka)

This material shall have the following characteristics:

1. It shall be free from water.
2. The various hydrocarbons composing it shall be present in a homogeneous solution.
3. It shall have a specific gravity at 77°F. of not less than 0.99.
4. It shall have a penetration (77°F., 100 g., 5 sec.) of not less than 50 nor more than 65.
5. It shall have an oven evaporation loss of less than 4 per cent. The penetration (77°F., 100 g., 5 sec.) of this residue shall be at least 50 per cent of the original penetration.
6. Its solubility at air temperature in carbon disulphide, for the following named products, shall be at least 99.5 per cent for pure bitumen products, 95 per cent for Bermudez products, 81 per cent for Cuban products and 66 per cent for Trinidad products.
7. The solubility of the bitumen, at air temperature, in 76°B. paraffin petroleum naphtha distilling between 140 and 190°F. shall be between 68 and 88 per cent.
8. The bitumen shall show between 8 and 17 per cent fixed carbon.
9. It shall show an open flash point not less than 375°F.
10. It shall not contain more than 4.7 per cent paraffin scale.
11. It shall show a toughness at 32°F. not less than 10 cm. Toughness is determined by breaking a cylinder of the material 1¾ in. in diameter by 1¾ in. in height in a

Page impact machine, (A. S. T. M. 1908). The first drop of the hammer being from a height of 5 cm. and each succeeding blow increased by 5 cm.

12. It shall have a ductility at 77°F. of not less than 25 cm. (Dow mold).

All bituminous material A shall be sampled by an Engineer of the Department of Highways and samples sent to the Bureau of Tests, Albany, New York.

Item 66—Specification for Bituminous Material A

Penetration Method

This material shall have the following characteristics:

1. It shall be free from water.
2. The various hydrocarbons composing it shall be present in a homogeneous solution.
3. It shall have a specific gravity at 77°F. of not less than 0.99.
4. It shall have a penetration (77°F., 100 g., 5 sec.) of not less than 110 nor more than 160.
5. It shall have an oven evaporation loss of less than 4 per cent. The penetration (77°F., 100 g., 5 sec.) of this residue shall be at least 50 per cent of the original penetration.
6. Its solubility at air temperature in carbon disulphide, for the following named products, shall be at least 99.5 per cent for pure bitumen products, 95 per cent for Bermudez products, 81 per cent for Cuban products and 66 per cent for Trinidad products.
7. The solubility of the bitumen, at air temperature, in 76°B. paraffin petroleum naphtha distilling between 140 and 190°F. shall be between 70 and 88 per cent.
8. The bitumen shall show between 8 and 17 per cent fixed carbon.
9. It shall show an open flash point not less than 375°F.
10. It shall not contain more than 4.7 per cent paraffin scale.
11. It shall show a toughness at 32°F. not less than 15 cm. Toughness is determined by breaking a cylinder of the material $1\frac{3}{4}$ in. in diameter by $1\frac{3}{4}$ in. in height in a Page impact machine, (A. S. T. M. 1908). The first drop of the hammer being from a height of 5 cm. and each succeeding blow increased by 5 cm.
12. It shall have a ductility at 77°F. of not less than 40 cm. (Dow mold).

All bituminous material A shall be sampled by an Engineer of the Department of Highways and samples sent to the Bureau of Tests, Albany, New York.

Item 67—Specification for Bituminous Material A

Hot Application

This material shall have the following characteristics:

1. It shall be free from water.
2. The various hydrocarbons composing it shall be present in a homogeneous solution.
3. It shall have a specific gravity at 77°F. of not less than 0.92.
4. When evaporated in the open air at a temperature not exceeding 500°F. until the residue remaining has a penetration (77°F., 100 g., 5 sec.) of 100, the amount of such residue shall not be less than 65 nor more than 75 per cent of the original oil. The ductility at 77°F. of this residue shall be not less than 25 cm. (Dow mold).
5. It shall have an oven evaporation loss of not less than 12 nor more than 28 per cent.
6. Its solubility at air temperature in carbon disulphide shall be at least 99.5 per cent.
7. Its solubility at air temperature in 76°B. paraffin petroleum naphtha distilling between 140 and 190°F. shall be between 83 and 97 per cent.
8. It shall show between 5 and 12 per cent fixed carbon.
9. It shall not contain more than 4.0 per cent paraffin scale.

All bituminous material A shall be sampled by an Engineer of the Department of Highways and samples sent to the Bureau of Tests, Albany, New York.

Item 68—Specification for Bituminous Material A

Cold Application

This material shall have the following characteristics:

1. It shall be free from water.

2. The various hydrocarbons composing it shall be present in a homogeneous solution.

3. It shall have a specific gravity of 77°F. of not less than 0.92.

4. When evaporated in the open air at a temperature not exceeding 500°F. until the residue remaining has a penetration (77°F., 100 g., 5 sec.) of 100, the amount of such residue shall not be less than 45 nor more than 55 per cent of the original oil. The ductility at 77°F. of this residue shall be not less than 25 cm. (Dow mold).

5. It shall have an oven evaporation loss of less than 30 per cent.

6. Its solubility at air temperature in carbon disulphide shall be at least 99.5 per cent.

7. Its solubility at air temperature in 76°B. paraffin petroleum naphtha distilling between 140 and 190°F. shall be between 85 and 97 per cent.

8. It shall show between 4 and 8 per cent fixed carbon.

9. It shall show an open flash point of not less than 100°F.

10. It shall not contain more than 4.0 per cent paraffin scale.

All bituminous material A shall be sampled by an Engineer of the Department of Highways and samples sent to the Bureau of Tests, Albany, New York.

Item 69—Specification for Bituminous Material A

Cut Back

This material shall have the following characteristics:

1. It shall be free from water.

2. The various hydrocarbons composing it shall be present in a homogeneous solution.

3. When distilled (A. S. T. M. Standard Method) up to a temperature of 400°F., the total distillate shall not be less than 22 nor more than 28 per cent by weight. The residue, poured from the flask immediately after the distillation, shall have the following characteristics:

(*a*) It shall have a specific gravity at 77°F. of not less than 0.99.

(*b*) It shall have a penetration (77°F., 100 g., 5 sec.) of not less than 150 nor more than 200.

(*c*) Its solubility at air temperature in carbon disulphide shall be at least 99.5 per cent.

(*d*) Its solubility at air temperature in 76°B. paraffin petroleum naphtha, distilling between 140 and 190°F. shall be between 75 and 88 per cent.

(*e*) It shall show between 8 and 16 per cent fixed carbon.

(*f*) It shall not contain more than 4.7 per cent paraffin scale.

(*g*) It shall have a ductility at 77°F. of not less than 40 cm. (Dow mold).

All bituminous material A shall be sampled by an Engineer of the Department of Highways and samples sent to the Bureau of Tests, Albany, New York.

Item 70—Specification for Bituminous Material A

Emulsion

Every proposal on asphaltic emulsion shall be accompanied by a sample of the emulsion, taken by an Engineer of the Department of Highways, from a factory lot of material of not less than 20,000 gal. The samples so submitted shall meet the requirements of the following specification.

The emulsion shall be homogeneous.

It shall mix with water in all proportions.

It shall be of such fluidity as to flow readily from the bung hole of a barrel.

Any material accepted at the time of shipment, which should prove to be defective within 30 days after date of delivery, will not be accepted or paid for by the Department of Highways, and will remain the property of the Contractor, except when separation has been caused by freezing.

The emulsion must be of such stability that it will remain constant and uniform while being combined and mixed with clean wet crushed stone sufficiently to thoroughly and uniformly coat the entire surface of each fragment of crushed stone, and while being manipulated and incorporated into the work. A test to determine the stability of the emulsion shall be made as follows:

A 500-g. mixture composed of 93 per cent of clean, drenched, No. 1 stone (¼ in. to ⅝ in.) and 7 per cent of emulsion by weight, shall show no appreciable separation of the asphalt contained in the emulsion after a vigorous mixing of 3 min.

When distilled up to a temperature of 500°F., the total distillate shall not be less than 24 nor more than 30 per cent. Not over 2 per cent of this distillate shall be oil. The residue from the foregoing distillation shall have the following characteristics:

1. It shall have a specific gravity at 77°F. of not less than 0.99.
2. It shall have a penetration (77°F., 100 g. 5 sec.) of not less than 150 nor more than 250.
3. Its solubility at air temperature in carbon disulphide shall be at least 95.0 per cent.
4. The solubility of the bitumen at air temperature in 76°B. paraffin petroleum naphtha distilling between 140 and 190°F. shall be between 72 and 92 per cent.
5. The bitumen shall show between 6 and 15 per cent fixed carbon.
6. It shall contain not more than 1.5 per cent of ash.
7. It shall not contain more than 4.7 per cent paraffin scale.
8. It shall have a ductility at 77°F. of not less than 40 cm. (Dow mold).

All Asphalt Emulsion shall be sampled by an Engineer of the Department of Highways and samples sent to the Bureau of Tests, Albany, N. Y.

Item 71—Specification for Bituminous Material T

Penetration Method

Bituminous material to be furnished under this item shall meet the requirements of either of the following specifications:

High Carbon

This material shall have the following characteristics:

1. It shall be free from water.
2. It shall be uniform in character, appearance and viscosity.
3. It shall have a specific gravity at 25°C., of not less than 1.20.
4. It shall have a melting point (R. and B.) of not less than 30 nor more than 36°C.
5. It shall contain not less than 12 nor more than 25 per cent of free carbon.
6. When distilled (A. S. T. M.), the distillate shall be:

Up to 170°C.	00.0 per cent
Up to 235°C. not more than	3.0 per cent
Up to 270°C. not more than	10.0 per cent
Up to 300°C. not more than	14.0 per cent

The residue from the foregoing distillation shall have a melting point (R. and B.), of not more than 75°C.

All bituminous material T shall be sampled by an Engineer of the Department of Highways and samples sent to the Bureau of Tests, Albany, New York.

Low Carbon

This material shall have the following characteristics:

1. It shall be free from water.
2. It shall be uniform in character, appearance and viscosity.
3. It shall have a specific gravity at 25°C. of not less than 1.16.
4. It shall have a melting point (R. and B.) of not less than 30° nor more than 36°C.
5. It shall not contain more than 5 per cent free carbon.
6. When distilled (A. S. T. M.), the distillate shall be:

Up to 170°C.	0.0 per cent
Up to 235°C. not more than	5.0 per cent
Up to 270°C. not more than	14.0 per cent
Up to 300°C. not more than	18.0 per cent

The residue from the foregoing distillation shall have a melting point (R. and B.), of not more than 75°C.

All bituminous material T shall be sampled by an Engineer of the Department of Highways and samples sent to the Bureau of Tests, Albany, New York.

Item 72—Specification for Bituminous Material T

Hot Application

Bituminous material to be furnished under this item shall meet the requirements of either of the following specifications:

High Carbon

This material shall have the following characteristics:

1. It shall be free from water.
2. It shall be uniform in character, appearance and viscosity.
3. It shall have a specific gravity at 25°C. of not less than 1.19.
4. It shall have a float test (N. Y. Test. Lab. Method) at 50°C. of not less than 75 nor more than 95 sec.
5. It shall contain not less than 10 nor more than 22 per cent of free carbon.
6. When distilled (A. S. T. M.), the distillates shall be:

Up to 170°C.	0.0 per cent
Up to 235°C. not more than	10.0 per cent
Up to 270°C. not more than	16.0 per cent
Up to 300°C. not more than	20.0 per cent

The residue from the foregoing distillation shall have a melting point (R. and B.) of not more than 75°C.

All bituminous material T shall be sampled by an Engineer of the Department of Highways and samples sent to the Bureau of Tests, Albany, New York.

Low Carbon

This material shall have the following characteristics:

1. It shall be free from water.
2. It shall be uniform in character, appearance and viscosity.
3. It shall have a specific gravity at 25°C., of not less than 1.14.
4. It shall have a float test (N. Y. Test. Lab. Method) at 50°C., of not less than 70 nor more than 90 sec.
5. It shall contain not more than 4 per cent of free carbon.
6. When distilled (A. S. T. M.) the distillates shall be:

Up to 170°C. not more than	1.0 per cent
Up to 235°C. not more than	12.0 per cent
Up to 270°C. not more than	20.0 per cent
Up to 300°C. not more than	25.0 per cent

The residue from the foregoing distillation shall have a melting point (R. and B.), of not more than 75°C.

All bituminous material T shall be sampled by an Engineer of the Department of Highways and samples sent to the Bureau of Tests, Albany, New York.

Item 73—Specification for Bituminous Material T

Cold Application

Bituminous material to be furnished under this item shall meet the requirements of either of the following specifications:

Blended Tar

This material shall have the following characteristics:

1. It shall be uniform in character, appearance and viscosity.
2. It shall have a specific gravity at 25°C., of not less than 1.14 nor more than 1.18.
3. The viscosity at 40°C. when tested by the Engler viscosimeter, shall not be less than 225 nor more than 300 sec. for the first 100 c.c.
4. It shall contain not less than 4 nor more than 12 per cent of free carbon.
5. When distilled (A. S. T. M.), the distillates shall be:

Up to 170°C. not more than	5.0 per cent
Up to 235°C. not more than	18.0 per cent
Up to 270°C. not more than	28.0 per cent
Up to 300°C. not more than	35.0 per cent

The residue from the foregoing distillation shall have a melting point (R. and B.), of not more than 70°C.

All bituminous material T shall be sampled by an Engineer of the Department of Highways and samples sent to the Bureau of Tests, Albany, New York.

Low Carbon

This material shall have the following characteristics:

1. It shall be uniform in character, appearance and viscosity.
2. It shall have a specific gravity at 25°C., of not less than 1.10 nor more than 1.13.
3. The viscosity, at 40°C., when tested by the Engler viscosimeter, shall not be less than 225 nor more than 350 sec. for the first 100 c.c.
4. It shall not contain more than 4 per cent of free carbon.
5. When distilled (A. S. T. M.), the distillates shall be:

Up to 170°C. not more than	5.0 per cent
Up to 235°C. not more than	20.0 per cent
Up to 270°C. not more than	28.0 per cent
Up to 300°C. not more than	35.0 per cent

The residue from the foregoing distillation shall have a melting point (R. and B.), of not more than 70°C.

All bituminous material T shall be sampled by an Engineer of the Department of Highways and samples sent to the Bureau of Tests, Albany, New York.

Item 74—Specification for Bituminous Material T

Cut Back

This material shall have the following characteristics:

1. It shall be free from water.
2. It shall be uniform in character, appearance and viscosity.
3. It shall contain from 0.0 to 3.0 per cent or from 14 to 22 per cent free carbon.
4. When the per cent of free carbon is from 0.0 to 3.0 the specific gravity of the material shall be from 1.10 to 1.15, and when the per cent of free carbon is from 14 to 22, the specific gravity of the material shall be from 1.15 to 1.22. The specific gravity tests being taken at 25°C.
5. The viscosity, at 80°C. when tested by the Engler viscosimeter, shall not be less than 80 nor more than 120 sec. for the first 100 c.c.
6. When distilled (A. S. T. M.), the distillates computed on the basis of the total bitumen in the material shall be:

Up to 170°C. not less than	4 per cent
Up to 235°C. not less than	18 per cent
Up to 270°C. not less than	26 nor more than 32 per cent
Up to 300°C. not less than	30 nor more than 35 per cent

The residue from the foregoing distillation shall have a melting point (R. and B.), of not more than 75°C.

All bituminous material T shall be sampled by an Engineer of the Department of Highways and samples sent to the Bureau of Tests, Albany, New York.

Asphalt, Topeka Mix, Amiesite, Etc.—The holes which develop in the bituminous mixing method type wearing surfaces should be repaired as follows: Excavate the old material at the defective spot the entire depth of course, so that the edges will present clean, vertical surfaces, these surfaces and the exposed foundation to be swabbed or painted with hot asphaltic cement or paving pitch, the hole then to be filled, with a mixture similar to that used in original construction whenever practicable, using sufficient quantity so that after consolidation by rolling (or tamping in case the extent of repairs is limited) the surface of the new patch will be ¼″ above the adjacent pavement. In case there is no local mixing plant available, or the limited extent of repairs do not justify expense of treatment as above, holes may be repaired with the mixture of crushed stone and cold patch asphaltic emulsion, as outlined for macadam surfaces.

MAINTENANCE (CONCRETE PAVEMENTS)

Quoted from Portland Cement Association Handbook

Maintenance should be systematic and imperfections given immediate attention.

Cracks and Joints.—The crack or joint should first be cleaned with a sharp hooked pick and stiff brush, care being taken to remove all loose particles. If the opening is too narrow to permit cleaning in this manner, it should be cleaned with an air jet from an automobile tire pump. After thorough cleaning, tar should be poured into the crack in sufficient quantity just to flush over the edges. The tar should then be covered with coarse dry sand. It will usually be found desirable to remove old joint material to a depth of ¼ to ½ in. below the surface of the concrete, so that new repair materials will have a good bond.

Care shall be taken not to pour the tar in such quantities that an unsightly wide strip is made on the surface. By bending the spout of the tar pot so that a long narrow opening is provided the tar can be poured in a very thin, narrow stream. It needs but a little attention to pour cracks so that a narrow ribbon of tar 1 to 2 in. in width is left.

Tar.—Refined coal tar should be used, having a melting point (½-in. cube method in water) of about 100°F. The tar should be heated from 225 to 250°F. at the time of application and may be applied by means of a sprinkling can with spray nozzle removed.

As a matter of interest the following quotation from the *Concrete Highway Magazine* describes the latest advance in Crack Repair Material:

A NEW JOINT FILLER FOR CONCRETE PAVEMENTS

By L. G. Carmick

Chemist, Bureau of Public Roads, U. S. Department of Agriculture

It has often been remarked that the appearance of concrete roads is greatly marred by the unsightly black streaks produced when cracks are filled with bituminous materials. Although in general the bitumen filler serves its purpose satisfactorily as a maintenance material the sharp contrast between the black bitumen and the light-colored concrete is displeasing, especially when the markings are extremely irregular. A light-colored filler would make the cracks much less conspicuous and would give the road that appearance of uniformity of surface so much to be desired.

Recently a search for such a filler has been made in the laboratory of the Bureau of Public Roads. The qualities desired are that it shall be sufficiently elastic to expand and contract as much as may be necessary, sufficiently durable to withstand the action of traffic, unaffected by water, easily applied, reasonably cheap, and of the same color as the concrete.

A material meeting these specifications was not easily found, though substances having some of the desired qualities were already available. Among substances tested may be mentioned the following: Substances of the general nature of putty; combinations of glue and molasses, such as are used in printing press rollers, but rendered more durable by means of formaldehyde or chromic acid; vegetable oils polymerized by sulphur chloride and combined with a mineral filler; and combinations of viscose with either sawdust or some

FIG. 162.—New patching material for concrete pavements.

other filling material, a large number of which were tried. None of these met the requirements. It was thought for a time that a satisfactory material has been found in chicle. This was dissolved in gasoline, about twice its weight of whiting added together with the necessary tinting pigments, and the result was a fluid that could be poured into cracks and which hardened with the evaporation of the gasoline. But when actually tried it did not withstand the action of traffic; it was too slow in hardening and, furthermore, it was too expensive to be really practicable.

At last, however, something has been found which really seems to possess all the desired qualities. But in making this statement it is necessary to add that practical experiments have not yet gone far enough to make it certain. Further modifications may be necessary when it has been tried out on a large scale and under varying conditions of traffic and climate. At present, on the basis of limited experiment, one is only justified in saying that it seems good.

The substance referred to is a compound of rubber, petroleum oil and pine rosin and a mineral filler. Crude, unvulcanized rubber is cut with about twice its weight of kerosene or light lubricating oil. This is added to melted rosin and thoroughly incorporated with it. The best proportion between rubber and rosin has not yet been determined. Probably this will depend upon the climate in which the material is to be used, for the compound should be neither too soft in summer nor too brittle in winter. In the vicinity of Washington 1 part of rubber to 12 of rosin appears to be satisfactory.

It is a matter of some difficulty thoroughly to incorporate the rubber and rosin. Mere stirring does not answer. It seems necessary to knead or pull the mixture when nearly cold, very much as taffy is worked. However, a perfectly smooth, homogeneous mixture can be obtained with patience and industry and one then has an exceedingly sticky, ductile

substance of a dark brown color, solid when cold and quite fluid at 110 to 125°C. While the mixture is fluid twice its weight of "blanc fixe" is added. This brings the color down to a light yellow, and then by the addition of a very small amount of carbon black the color of portland cement concrete can be matched very closely. The "blanc fixe" referred to is precipitated barium sulphate, a white pigment largely used in the paint industry. It is better than ordinary barytes, or natural barium sulphate, because it is more opaque. So far it has been found to be the most satisfactory pigment for the purpose, as it is unaffected by the highly acid rosin compound and is fairly cheap.

This crack filler can be manufactured at the present time at a cost for materials that should not exceed 10c. a pound. It can be shipped in barrels or other containers as easily as asphalt. It is melted at the roadside in open kettles and poured into the cracks. No delay of traffic is necessary, as it hardens immediately. While the cost is undoubtedly greater than asphalt it is, after all, but a small item in the cost of a concrete road, and the greatly enhanced appearance due to the absence of unsightly black streaks would justify the slightly higher price.

A considerable quantity of the material is now being manufactured for the Bureau and it is intended to give it a thorough test in the near future.

Surface Pockets.—A pocket in the surface, 1 to 3 in. in size, due to soft aggregates or the disintegration of a lump of clay, or a piece of coal or wood, should first be thoroughly cleaned. It should then be filled with hard, small aggregates, ranging in size from ¼ to ⅜ in. Hot tar should then be poured into the opening until the tar is flush with the surface. Very coarse, dry sand should then be sprinkled on the tar immediately.

A cold mix of small stone and emulsified asphalt has been successfully used for this type of repair work. (See page 430.)

Slight Depressions.—If for any cause a slight depression has formed, it can be coated with tar, very coarse sand added, covered with tar, and the whole covered with sand and tamped into place.

FIG. 163.—Patching cracks in concrete pavement. Poor method: note the wide unsightly smear of bituminous material.

Replacements.—If it is necessary to cut a hole through the entire thickness of the concrete slab, gravel should be placed in the subbase and thoroughly rammed, so as to form a compacted base on which the new concrete will rest. Where water has been allowed to stand in such a place, it should be compacted after the water has been removed and just before laying the concrete. Before placing the concrete the sides of the opening should be painted with a mixture of neat cement and water.

The consistency of the concrete should be sufficiently stiff to require considerable tamping to bring water to the surface so that it may be possible to ram it thoroughly into place. A small tamp, made of a 2 by 1-in. stick, 18 in. long, should be used to ram the concrete adjacent to the edges.

After the concrete is rammed into place it should be struck true to the surrounding surface. A repair made in this manner cannot be told from the old pavement after a few months' use.

A new patch should be kept moist for at least 4 or 5 days, and protected from traffic at least 10 days.

Equipment that has been found to work very satisfactorily and economically for the maintenance of concrete roads by the Illinois Division of Highways, Department of Public Works, is shown in Figs. 158*A* and 158*B*, page 425.

Block Pavements.—Block pavements of brick, stone, asphalt, etc. properly constructed should not require repairing for a considerable term of years; cracks which develop should be grouted with hot paving pitch or asphalt binder; areas which settle, thereby breaking the bond of the grouted joints resulting in crushing or cobbling the blocks, should be taken up, the sand cushion reformed, all sound blocks cleaned and relaid, being turned over where necessary, any broken blocks to be replaced by new whole ones, joints then to be grouted with Portland cement grout preferably, if the original pavement was so constructed, otherwise the joints may be poured with hot paving pitch. It should be noted that repairs with fresh cement grout require to be protected by barricades for a period of about a week, so that such repairs should be confined to one side of the pavement in long stretches, leaving the other side available for traffic; where the repairs are limited in extent and barricades are especially undesirable, the patch may be covered with 2 in. of earth and further protected by planking during the time required for the grout to set. Where joints are poured with paving pitch, traffic need be diverted only during the time of actually making the repair; this is a decided advantage.

Rigid Pavement Shoulders.—Observation demonstrates that horse traffic on steep grades leaves the pavement and seeks the earth shoulder, so that so far as practicable these shoulders should be improved by widening, and by graveling or covering with broken stone to avoid excessive rutting, also that on sharp curves the tendency of motor vehicles is to cut close to the inner edge, making it well for this reason to stone or gravel the shoulders at these points.

Along the edges of the rigid types of pavement, block and concrete especially, traffic usually develops a deep rut which if neglected becomes dangerous to rapidly moving traffic; this rut should be kept filled with gravel or broken stone. Excess material when removed from the shoulders should be so disposed of as to widen embankments and flatten slopes.

Snow Removal.—On main roads between large cities snow removal in winter has become part of the regular program. In many districts automobile trucking relieves rail congestion and is needed even more in winter than in summer. The Maintenance Departments are in a position to handle this work with their organized forces and equipment which

are idle at this time of year and the necessary expense is certainly worth while to make the main road passable for trucks the year round. The only way successfully to handle snow is to get right at it as soon as a storm starts and keep working. If bad drifts are permitted to form it is very expensive to clear the road. Snow fences help to prevent drifting. In Monroe County New York the cost per mile per winter to keep the main roads passable for motors ranges from $50 to $100. The usual equipment consists of trucks equipped with special plows.[1] Hand shoveling is at times necessary where bad drifts form. A permanent fund of $75 per mile per year is proposed with any unexpended balance for easy winters carried over for use in exceptionally hard winters. Four hundred miles are to be kept open in this county and the popular approval of expenditure for this work assures a continuation of this phase of highway maintenance.

MAINTENANCE OF EARTH, SAND-CLAY, AND GRAVEL ROADS

Low Type Roads.—The maintenance of these roads consists in keeping the grass and weeds cut, the ditches clean, culverts clear, overhanging trees trimmed and the surface of the traveled way scrapped and dragged. One shaping with a blade road machine in the spring generally is all the heavy work required the rest of the work being done with road drags, hones, planers, etc., at frequent intervals during the balance of the year.

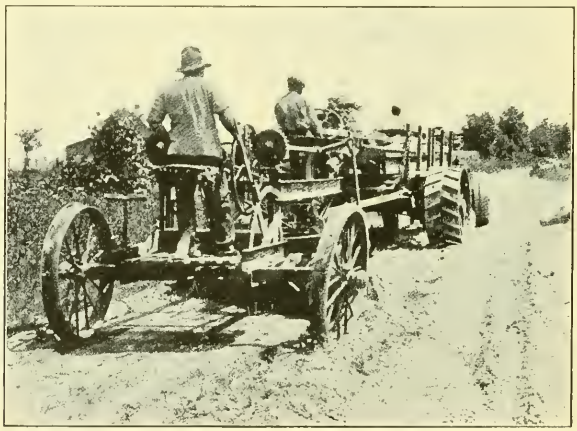


Fig. 164.—Earth road maintenance with road machine hauled by trucks.

On sand-clay and gravel roads surfacing material is added to fill holes and ruts or better the wearing surface.

There are two general systems: The contract system which lets short strips of road not over 4 miles in length to farmers along the road and the

[1] Each should be able to care for 10 miles of road with occasional extra help.

patrol system which is taken care of by a steady patrol gang which handles from 10 to 20 miles. The contract system is explained in the

FIG. 165*A*.—Modern steel drags.

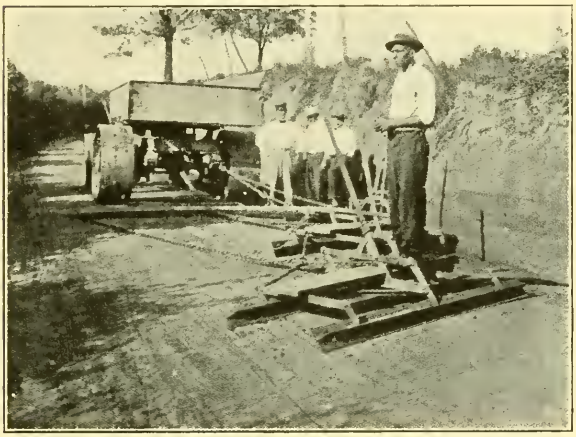


FIG. 165*B*.—Modern steel drags.

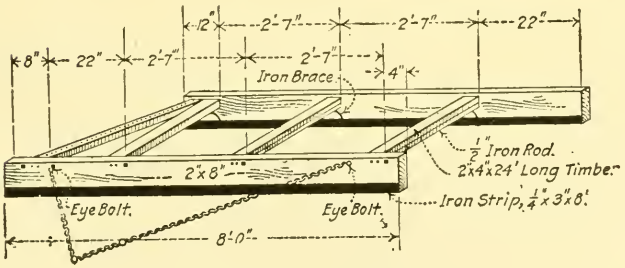


FIG. 166.—Road drag.

quotation from the 1917 Year Book of the American Highway Association, page 453. The patrol system is referred to throughout the chapter in various quotations.

Earth Roads.—Road machine blade scrappers are familiar to all readers. The road hones, planers, etc., are not so well known and their construction is shown in Figs. 166 and 166*A*. Steel drags can now be obtained. Their use in earth or gravel road maintenance is explained in the following quotation from the United States Forest Road Manual.

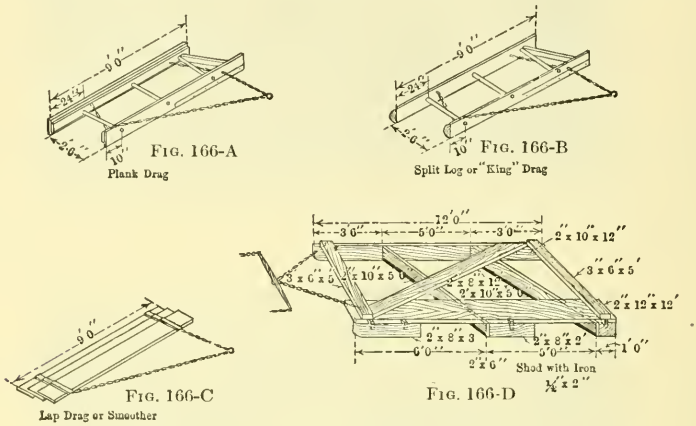


Fig. 166*A*–*D*.—Road drags and planers.

EARTH ROAD MAINTENANCE (U. S. FOREST ROAD MANUAL)

Maintenance is the most important item of work to be considered in road management. The smaller allowances for systematic maintenance, as they are being included in the annual road budget alongside the unlimited number of those for periodical repairs, tend to give it a place of least consideration and again its consideration and planning is evaded as much as possible for it is the never-ending consideration of continuous annual work and expense. It is always admitted that the degree of efficient use we derive from anything constructed for practical utilization, depends on the amount of effective maintenance it receives. Therefore, roads which are most widely used and exposed in all their parts to the worst of elements relatively should receive the highest degree of such attention, and moreover the higher the type of construction and the more it costs, the more marked attention will it require.

However, it is most gratifying to find that the old ideas of taxpayer and user are rapidly disappearing, making way for the installation of practical system for the efficient retention of the better roads—as they are now being constructed. We are gradually beginning to learn that the stability and usefulness of a road is not forever established, even when the best of supervision and authorities declare and approve or have made the construction strictly up to the standard and with ample drainage provided—but that each mile of construction should be followed immediately with a mile of maintenance. Besides eliminating the difficulties and discomforts of travel, which seem only a benefit to the traveler, is in reality an economical benefit to everyone, directly or indirectly—maintenance will do away with all the worries to the management and effectively prevent so much of this misapplied criticism to construction features. Finally the results of maintenance encourage more road-building, whereas its lack discourages it.

There is no type of road that can be considered permanent, and an earth road or one bedded in the natural material—which is wholly as important as the higher grade roads, or even more so—is the cheapest to maintain in its original condition. The complete maintenance of an earth road means simply the retention of the drainage facilities that were provided in a completed and properly constructed piece of road work. Furthermore the

experience and the attention given to the road in constant maintenance will show where ample drainage was not sufficiently provided; and again showing its importance, constant maintenance secures this necessary drainage with the least costs and at the proper time—before serious damage is done and heavy repair costs result. The time to begin the maintenance is immediately after the road is constructed, and its degree of efficiency will depend on what in the way of money or assistance is constantly provided or made available to meet sudden contingencies. The work must be done at the right time and in the right way to get the best results.

Ample drainage begins with taking the water off the road and continues with taking it along the road and away from the road. Constant maintenance by dragging secures this primary step in the drainage system, and also a hard and smooth surface for travel. The dragging preserves the crown, which is kept in the traveled way for no other purpose than to shed water. It then follows that this water will be taken away from the road through the further efforts of constant maintenance in keeping the ditches and culverts open.

To maintain properly and economically a certain road or set or roads an organization for doing the work should be affected. On a country or mountain road a patrol consisting of two teams and two men for one part and one team and one man for the other part of the season should be able to care for 15 to 20 miles. It will be found though that a newly constructed road will require heavier maintenance for the first year or two, thus reducing the number of miles for this patrol. One or more such outfits could be applied to a longer road or a larger system and kept under the same supervision. These patrols keep theditches clean and the culverts open, haul surfacing materials, *i.e.*, clay onto sandy portions and sand or gravel onto clay, keep the right-of-way open to sun and wind; and are on hand to drag the road after each rain. Two teams are provided only in cases where there is no extra help available along the road to assist in the dragging, otherwise one team would be sufficient. However, if the teams are government-owned, two teams should be used, as the added costs for the extra team are small and will in most cases prove cheaper than hiring. The two teams can be used on one dray or two depending on the ruling grades in the road.

In early spring when the winter snows are going off, the supervisor and such extra assistance as is necessary should be made available early to see that the snow water is being cared for—that it is running down the ditches and into the culverts, and not down the wheel tracks and over the banks of the road. Later he should have a small gang of men making the necessary repairs that might occur while the frost is coming out of the ground and from wash and water-breaks. A light grader should be at hand especially on sidehill roads to clean the ditches of material broken off or rolled down the banks and to restore badly depleted crowns, after which the drag can be used for the remainder of the season to preserve this perfected condition.

A good foreman for this should be a man who as well as to take a hand in the work, should be able to plan the work and keep in touch with the maintenance needs and move his men economically to the first necessary pieces of repairs.

Dragging is the cheapest and most effective method of maintaining roads constructed of earth, top soil, sand-clay or gravel. The drag is a very simple and inexpensive implement and when used properly gives surprising results.

Properly used and at the right time the road drag performs four distinct offices: (1) By moving at an angle to the traveled way it tends to produce or preserve a crowned cross-section; (2) if used when the material of the surface is not compact and hard, it tends to reduce ruts and other irregularities in the road by moving material from points which are relatively high to those which are relatively low; (3) when used after a rain it accelerates the drying out of the road by spreading out puddles of water and thus increasing the surfaces exposed to evaporation; (4) if the surface material is in a slightly plastic state, dragging smears over and partially seals the so-called pores which naturally occur in earthy material, and thus makes the road surface more or less impervious to water.

If used improperly or at the wrong time, the drag may do actual injury to a road. Dragging a very dry road, for example serves to increase the quantity of dust and may do additional damage by destroying the seal produced during previous draggings. If, on the other hand, the road is very wet and muddy, the irregularities in the surface are likely to be increased rather than diminished. The common defect in road dragging is to regard the road drag as a road-building tool, and to expect one or two trips to put the road in shape for the season.

NOTES ON MAINTENANCE

1. In filling bad ruts and mud-holes, it is best to use the same material that the road bed is composed of, otherwise an uneven surface will result, oftentimes, of course, the road bed of clay can be improved by scattering sand or gravel over it more or less evenly, or if of sand by the same use of clay, but not by filling the ruts with these applications. Filling with rock will effectively close a mud-hole but the next season will find two more mud-holes, one on either side of this hard place formed by filling the first.

2. On sidehill roads, after light snows have fallen during the season, the inside ditches should be opened of the snow immediately in order that the water from the melting snow will run down the ditches instead of the wheel tracks. This is especially necessary where steep grades occur to prevent heavy wash and loss of crown in the traveled way, and water breaking over the outside bank. The snows, usually, being light, this can be done by drawing the drag down the ditch with a large skew angle or better with a small ditch-cleaner, the A-drag or go-devil.

3. In a grazing country very often it occurs that salting grounds have been used near or along the roads. These should be removed for cattle climbing up and down the banks and walking along the ditches can cause considerable unnecessary damage to the road. During the season of cattle or sheep drives the men on maintenance should see to it that the herds or bands, if they have to use the road, use the traveled way and not the banks and do as little damage as possible. If serious damage is done they can make immediate reports, if owners are obligated to repair such damages on public roads.

4. Outer bank slopes of earth that are continually eroding, should be protected by sowing to grass, or any other plant that will mat and not be objectionable to occupants of lands along the road.

5. Keep the ends of the culverts free from drifting weeds and debris and clean the catch-basins of silt and other deposits.

6. Remember that the chief repairs should be looked after in the spring when the soil, being moist and easily worked, will compact readily under the drag and traffic. There is little use in attempting to do much in July and August to the road bed proper, for the soil is so dry that it is difficult to shape properly and most of that moved will blow away in the first wind.

NOTES ON DRAGGING

1. Use the drag often and if the very best results do not come at first trial, do not quit. First-class results can be attained.

2. Dragging is always done after rains, melting snows, or thaws, just after the ground has lost its stickiness, when the material will slide easily along the face of the drag and pack well; but not when it becomes dry in any one place. Different road surfaces and varying conditions will demand different times of application, the knowledge of which will come through faithful and persistent use and observation.

3. It requires a careful and skilful operator to get good and quick results, one who knows or can learn how to hitch to it, and where and how to ride it. Hitch so that the drag will travel at an angle of 45° with the center line of the road, and do not try to cut too much material at one operation. The amount moved depends wholly upon the length of hitch and position of driver. A long hitch will move more earth than a short one. When a hard spot must be cut, the driver throws all his weight on the front blade; when a low place must be filled he moves back. These operations on patented steel drags are facilitated by changing the angle of the blades from a vertical. Step quickly to the opposite end of the drag from which you wish to deposit material into low spots.

4. Drive the team at a walk and ride the entire distance. The drag should begin at the ditch line and proceed toward the center or crown. If the crown becomes too great, reverse the skew angle of the drag. Do not try to drag too wide a section at one operation.

5. Do not try to drag too long a section. So much depends on the time the drag is used, that there is danger of dragging the road too wet at one end and too dry at the other. Learn to select those sections which dry before others and drag them first.

6. Drag the road during or directly after one of the light snow falls just before it freezes up for the first time, as it will be in better condition to go through the winter and better able to shed water during the spring thaw.

7. Very little improvement will be noticed after the first trial, and many trips will have to be made the first year after construction. The second year, less dragging will be required and the road ought to improve continually.

The following quotation from the 1917 Good Roads Year Book shows the Kentucky methods and approximate cost of maintenance.

Maintenance by dragging is most successful when well organized. The results obtained by good management in Hopkins County, Kentucky, are frequently cited as indications of this, and for this reason the following account of the work there is quoted from a report by the Kentucky department of highways.

In 1912 a county engineer was appointed. The county roads were measured under his supervision and 2-mile sections designated, and in January, 1913, drags were started on about 100 miles of the county roads. This original contract was only for dragging the roads, which work was to be done 4 times between January 1 and April 1, at a cost of $10 to $12 per mile. As the sections dragged were not continuous, the citizens at once appreciated the difference between the maintained road and that which was not maintained. Consequently the next contract, which called for dragging and also for cleaning the ditches for 6 months, until November, 1913, resulted in contracts for 150 miles of road and at a reduced cost. In November, 1913, a contract substantially like that now in use was adopted and the time of the contract was for 1 year, or until November, 1914. Over 200 miles were maintained this year at an average cost of $28 per year per mile. For the year from November, 1914, to November, 1915, the benefit of the maintained roads was so well understood by the citizens than 560 miles were under contract at an average cost of $24.35 per mile per year.

In November, 1915, a 2-year contract was entered into, which the county may revoke for non-performance of the obligation at the end of the first year. About 520 miles are now under contract, at prices ranging from $12 to $40 per mile per year, the average being $22.10. It is expected this mileage will soon be increased. Originally a contractor was allowed to have charge of 8 miles, but now he is not allowed to contract for more than 4 miles of road. Under the 1915 contracts the contractor must trim the branches which overhang and interfere with travel on the roadway; keep the ditches clean, free from obstructions, and at all times capable of carrying the water. He shall by June 1 each year grade the roads with dump scraper, grader, drag and ditcher, or in any way he may see fit, so that the center of the roadway shall be crowned so that the water will flow from the center of the road to the side ditches, and at no place will the water stand on the road or run down the road. The road shall be dragged from ditch to ditch at each dragging, when the road is wet, but not sticky.

A record of the number of draggings is kept by the county engineer on cards which, before mailing by the contractor, are countersigned by the rural route carrier or a reliable citizen. The contractor also hauls material and constructs all culverts and bridges of 10-ft. span or under, and keeps the approaches to and the floors and abutments of all bridges and culverts on his road in good traveling condition. An analysis of these contracts shows that where the contract has been faithfully executed there is a decrease each year in the cost per mile, mainly because the farmer contractor has learned from experience that continuous maintenance makes a lower cost of time and labor each succeeding year.

Cost.—The cost of earth road maintenance ranges from $20 to $200 per mile per year. A fair average is approximately $50 to $100 under light volume of traffic per mile per year for ordinary farming county and $100 to $200 per mile per year for mountain roads.

Sand-clay Roads.—The methods and character of work are the same for the sand-clay maintenance as for ordinary earth roads. The cost is generally less. The following quotation from the Alabama State Highway Report indicates the usual procedure.

SAND-CLAY ROADS

No cheap road can be maintained as easily and at as small an annual cost as a well-constructed sand-clay road. It responds readily to a road machine and the surfacing material is usually very convenient. Like all others though it is neglected until extensive and expensive repairs become necessary. If a sand-clay road which has been intelligently constructed is kept dragged at reasonably frequent intervals, say three times a month during December, January, February, March and April, and during rainy periods in the other months, it will give excellent service and serve all practical purposes. If too much sand is in the surfacing material the road will tend to ravel or disintegrate and it becomes necessary to add a small amount of clay to the sandy section. A thorough harrowing should then be given the surface, after which the road should be thoroughly machined or dragged until the proper cross-section is obtained. Likewise, too much clay may develop in wet weather and the addition of sand becomes necesssary. Sand can be incorporated in like manner as the clay. In very wet weather, traffic will incorporate the sand fairly well and it frequently becomes necessary to add sand to prevent slipping, when artificial mixing would be difficult.

Gravel Roads.—Gravel roads require patrol maintenance for good results. The road should be shaped with a road machine blade grader in the spring while soft and plastic and kept in shape by dragging. Gravel must be added continuously to fill holes and ruts. Shoulder, ditch and culvert routine cleaning is the same as for any maintenance.

The following quotation is from Instructions to Patrolmen in New Hampshire which is famous for its gravel roads.

Each patrolman must supply a horse and dump cart, shovel, pick, hoe, rake, stone-hook, axe, iron bar, iron chain and tamp. Special tools are furnished by the State Highway Department.

One dragging in the spring is worth two in the summer. It is better to drag a mile of road several times and get it in good condition, than to drag 2 or 3 miles and not finish any part of it. Don't drag a soft section when it is so wet that the first vehicle to pass will rut it all up. First fill the holes and ruts with new material and then drag as the surface dries out. Every patrolman should have material dumped in small piles along the side of his section so that on a rainy day he can at once fill all holes and ruts in which the water is collecting.

When the weather is unsuitable for dragging, as during a dry spell, all patrolmen should cart on all the new material possible in order to fill all ruts and holes and resurface worn sections. Carting is very essential during dry periods and should never be neglected. Whenever a patrolman is in doubt as to what to do next the general rule is to cart new material, for all roads are wearing out under travel and it is necessary that the surface be continually renewed to take the place of the old material that is thrown out as mud or blown away as dust.

Save all the sods, leaves, rubbish, stones and refuse that you clean off your road and dump this waste material in places where the bank is steep so that by flattening the side slope there will be no need of a guard-rail, or dump the material back of a present guard-rail so that later this guard-rail can be removed.

The necessity for patrol maintenance is shown by the following extract from the Iowa Specifications.

MAINTENANCE OF GRAVEL ROADS

County engineers' and supervisors' attention is called to the fact that both Class A and Class B gravel roads require constant and systematic maintenance at all times. Special attention should be given such roads for the first year following their construction. During this period the gravel is sure to become rutted, wavy, and scattered if it is not maintained in the most careful manner.

Hauling gravel and dumping it on the road does not produce a gravel road. The most important part of the construction work lies in the attention which the road receives while the gravel is being compacted. A road newly surfaced with gravel is nothing but a possibility. The success or failure of such a possibility depends very largely on the attention which it receives during its first year. The frequent use of a planer or blade grader will prevent the formation of ruts and waves. This work should be done while the gravel is wet, as better results will be secured.

The scattered gravel should be brought back on the surfacing and the earth shoulders built up to hold this material in place. Additional gravel should be added to replace that worn away and to fill any depressions due to settlement.

The Commission strongly urges that the patrol system of maintenance be adopted for all gravel roads. The patrolman should spend all his time on the road. It is only by such a system that definite responsibility can be fixed. Patrol maintenance should extend not only over the first year after the gravel surface is placed, but also throughout the succeeding years. It should extend to the side ditches, earth shoulders, culverts, and all other parts of the road as well as to the gravel surfacing.

While the patrol system of maintenance is urged for all gravel roads, it is absolutely necessary for Class B gravel roads. These specifications have been prepared with that idea in mind.

The Commission will approve the construction of Class B gravel roads on the county system only on condition that an adequate patrol maintenance will be established promptly after such road is placed in service." IOWA HIGHWAY COMMISSION.

The following quotation from a paper by Otto S. Hess published in Engineering Contracting gives an excellent description of up-to-date methods of gravel road maintenance under heavy traffic.

GRAVEL ROAD MAINTENANCE WITH "SPRING SCRAPERS"

Method Employed in Kent County, Michigan, Described in Paper Presented Feb. 14, 1923, at 9th Annual Michigan Conference on Highway Engineering

BY OTTO S. HESS,

Road Engineer, Kent County

The system of maintenance which will be outlined in this paper has been developed in Kent county during the past two years, and the ensuing remarks will apply more particularly to Kent county rather than to the State as a whole.

While this system would undoubtedly operate to good advantage in a great many counties, it is not advocated by the writer as a cure-all for the many difficulties which are encountered in the maintenance of gravel roads.

Highways of Kent County.—At the present time, Kent county has 252 miles of improved gravel roads on the county road system. Of this mileage, 90 miles lie on the state trunk lines, and the remaining 162 miles are county roads. In the early maintenance season of 1920, all of this mileage was taken care of by teams hauling light graders or floats. About this time, the county tried out a maintenance machine which was new at that time but quite well known throughout the state and even outside the state at the present time. This machine is the spring scraper which is used as a truck attachment and operates as a blade scraper underneath the middle of any truck.

The first "spring scraper" was so successful that the team patrols were gradually replaced by the so-called truck patrols, until at the beginning of the maintenance season of 1922, all of the teams had been replaced and the entire mileage of 252 miles of gravel roads was being kept smooth by nine trucks with scraper attachments, making an average of 28 miles per truck.

Work of Truck Patrols.—Under the present system, Kent county is divided into four maintenance districts. The trucks are operated from a central point in each of these districts. A very thin layer of finely screened gravel is kept on the surface of the road at all times. By scraping this surface often enough it has been found possible to maintain a surface which is smoother to ride on than most pavements. The number of times per week or per day which is necessary to scrape the surface in order to keep it in this con-

dition is dependent on the weather and the volume of traffic, but more particularly on the volume of traffic. The amount of scraping, and, consequently, the cost of maintenance has been found to be very nearly in direct proportion to the volume of traffic using the road.

The type of trucks which has been found to be most economical in Kent county are those in the 2- to 3-ton class. These trucks carry a 10-ft. blade, which is placed under the truck in a diagonal position, and travel at a speed of 8 to 12 miles per hour. The blades are 10 in. wide to start with, but are worn down with about two weeks steady use to a width of 3 or 4 in.

Each truck on scraping work is able to travel from 60 to 90 miles per day. Each truck scrapes a path approximately 9 ft. wide. With reference to the quality of work done, it can truthfully be said that the old team patrol system was never able to keep the roads as smooth as they have been maintained by trucks. In fact, the gravel roads of Kent county have never been in as good condition as they were in 1922, when they were maintained entirely by trucks.

Saving Effected by Substituting Trucks for Teams.—Some idea of the saving which can be effected by substituting trucks for teams can be obtained by comparing the daily costs of each. In actual practice it was found that one truck would, on the average, replace six team patrols. In 1922, teams with drivers cost $6 per day, making $36 per day for six team patrols. One truck could be hired, with driver, at $20 per day. This shows a direct daily saving on the pay roll of $16 per day per truck. Assume that the number of days worked during the season was 200 and we have: 200 days × $16 × 9 trucks = $28,000 which is the direct pay roll saving during 1922. As a matter of fact and record, the actual saving was about $30,000 for the reason that Kent county operated its own trucks at about $15 per day instead of hiring them at $20. As a further saving which is effected by the scrapers, it should be remembered that it is necessary to buy and maintain only one scraper as compared with six outfits of teams. Another advantage, which is by no means unimportant, is the fact that the trucks can haul gravel or other materials and scrape the roads at the same time. This is a feature which saves many thousands of dollars in a year's time, and is not obtained by any other type of road maintenance equipment in use today.

Cost of Maintenance.—In order that one may obtain some idea of what this maintenance work costs, Table I has been prepared, showing the cost per mile, volume of traffic, and cost per vehicle mile for all of the gravel roads on the state trunk line system in Kent county:

MAINTENANCE COST OF GRAVEL ROADS ON STATE TRUNK LINE SYSTEM IN KENT COUNTY

Sec.	No.	Mileage	Total cost	Cost per mile	Average daily traffic	Number vehicle miles	Cost per vehicle mile
13	1	7.50	$ 9,139.50	$1,218.60	1,791	2,686,500	$0.00340
13	3	7.00	10,634.76	1,519.25	1,810	2,534,000	0.00419
13	4	5.00	8,235.54	1,647.11	2,025	2,025,000	0.00460
13	5	14.50	12,077.29	832.11	838	2,430,200	0.00496
37	8	2.00	1,414.41	707.20	594	237,600	0.00595
37	10	5.50	3,819.89	694.53	594	653,400	0.00584
16	14	14.00	17,358.33	1,239.88	1,305	3,654,000	0.00475
39	16	11.50	5,836.71	507.54	594	1,366,200	0.00427
39	18	1.50	446.22	397.48	680	204,000	0.00218
44	20	13.50	12,380.47	910.77	1,079	2,913,300	0.00415
66	15	2.50	958.55	383.42	.....	No traffic count	
54	23	14.50	9,610.89	662.82	.....	No traffic count	
Totals, averages.....		99.00	$91,912.64	$ 928.31		18,704,200	$0.00435

In explanation of the table, the writer would advise that the total number of vehicle miles for any section was obtained by multiplying the average daily traffic (as determined by a traffic census taken in July and August) by 200, and then by the number of miles in the section, assuming that 200 times the average daily traffic in the summer would represent the total traffic for the year. This shows that the average cost per vehicle mile on the state trunk line gravel roads was a little less than a half cent.

Cost.—We are indebted to F. R. White, Road Engineer of the Iowa Highway Commission for the following information in regard to the construction and maintenance cost of about 400 miles of Class B gravel roads (see Plate 61, page 181). These roads are constructed at a cost slightly above $1,000 per mile (1913). The cost of maintenance depends very largely on the volume of traffic and the location of gravel. However, where there is an average of 200 to 300 vehicles per day and the gravel can be obtained within 3 miles of the road the yearly cost of maintenance is about $150 per mile.

In New York State where the roads are oiled to care for a somewhat larger volume of traffic 200 miles of high-class gravel roads cost approximately $700 per mile per year to maintain.

A fair average maintenance cost per mile per year for double track gravel roads is probably from $200 to $300 under fairly heavy traffic (300 to 400 vehicles daily).

RECONSTRUCTION

Resurfacing or reconstruction is resorted to when normal maintenance methods with reasonable yearly expenditures fail to keep the highway in proper condition for traffic. Economic limits of yearly maintenance costs and maximum permissible degrees of roughness were discussed in Chap. II, pages 150 to 151.

Reconstruction includes the restoration or improvement of pavement conditions in regard to strength, width, and perfection of surfaces; the retention of a safe and convenient grading section, ditch to ditch, and sometimes considers alignment changes to increase safety and reduce objectionable grades. Relocations in the matter of alignment and grade were discussed in the first book of this series. Existing practice in pavement reconstruction generally fulfils the principles of improvement of surface and pavement width but often neglects the item of the retention of a safe grading cross-section ditch to ditch. That is, proper shoulder and ditch work is often slighted which results in added danger from narrow soft shoulders and deeper ditches. Existing ditches are often deepened to get shoulder material instead of providing an item of borrow excavation for suitable gravelly soil for the necessary shoulder fills.

The cost of reconstruction programs is affected by type selection and by the promptness with which roads are treated when they show the preliminary evidence of some weakness. Delay, due to shortage of

funds, is probably the most active cause in raising reconstruction costs (see page 461).

Economic Type Selection.—Reconstruction programs are overshadowing original construction in many of the states having state aid programs over 15 years of age. The economic selection of pavement type for reconstruction is an entirely different proposition than for original construction. Economic reconstruction must utilize to best advantage the existing pavement. To do this, it is generally undesirable to change the type of foundation although it is often desirable to strengthen the foundation and better the surfacing particularly to get rid of oiling maintenance on main roads. That is, if the existing road is of the macadam type serving Class IIA, II or III traffic, it is rarely desirable to change to the rigid type of pavement although it may be desirable to strengthen the existing macadam and surface with an asphaltic concrete or block pavement in order to eliminate the oiling nuisance. If an old macadam practically shot to pieces serves Class I traffic, it is evidently desirable to change type.

All of our original roads become in time merely foundations for easily repaired renewable surface courses which meet the demands of traffic. Adequate foundation strength can be achieved by either sufficient depth of macadam or sufficient depth and strength of cement concrete. After adequate foundation strength is attained by either method, satisfactory surfaces can be maintained at about the same cost per year. As discussed in Chap. II (Design), the thickness of cement concrete foundations is about the same whether laid on old macadam or new grading; where an old macadam pavement exists and the reconstruction type is changed from a flexible foundation to cement concrete, we have to throw away most of the value of previous pavement work which usually raises the cost of such work way beyond the method of retention of foundation type with necessary additional strengthening and improvement of surface.[1] To illustrate briefly from Division 7 New York State, 1922 cost conditions. Old firm waterbound roads serving Class III traffic can be resurfaced with waterbound macadam for about $0.80 per square yard or with penetration bituminous macadam for about $1.00 per square yard. If we change type and use the thinnest cheapest rigid pavement we dare use 6-in. reinforced cement concrete, it costs about $2.70 per square yard. A good many of our old waterbound roads are too weak for modern traffic and require additional strengthening over and above a new 3-in. top. This additional depth rarely requires more than a 3- to 5-in. middle rein-

[1] The depth of concrete bases or pavement laid on top of an existing old macadam road is about 1 in. less than where laid on ordinary earth subgrade (see Chap. II). This reduces the cost of the concrete pavement about $0.50 per square yard whereas the old macadam if utilized to full advantage as part of a flexible type pavement is worth about $1.50 per square yard.

forcing course costing from $0.40 to $0.70 per square yard. For such roads, retention of waterbound type with adequate strength costs about $1.20 to $1.50 per square yard and adequate strength with improved penetration bituminous macadam top costs from $1.40 to $1.70 per square yard while change of type costs at least $2.50 to $2.70 per square yard. Under this class of traffic, the difference in first cost far outweighs the minor difference in yearly surface maintenance of the two types (see Maintenance Costs, page 392).

Under Class II and IIA traffic, firm macadams can be resurfaced with penetration macadam for about $1.20 per square yard and with asphaltic concrete or small cubes for from $1.50 to $1.80 per square yard. Change of foundation type costs about $2.70 to $3.40 per square yard. For the weaker macadams, the cost of proper reconstruction, using necessary additional reinforcing middle course, probably averages about $1.90 per square yard for penetration macadam and about $2.20 to $3.00 for low maintenance cost surfaces such as asphaltic concretes and stone or brick cubes. The advantage still lies with retention of foundation type considering the sum of reconstruction costs and yearly maintenance.

Under Class I traffic, the advantage falls on the side of change of type and for these roads, we have no hesitation in adopting the policy of rigid foundation type. In this territory, however, we have at present 860 miles of improved roads of all types serving all classes of traffic. The table below indicates the relatively small mileage on which it is desirable to change foundation type namely about 5 to 15 per cent of total mileage at present constructed (see Frontispiece classification map) *but this percentage may be radically changed by delay in necessary reconstruction* (see page 461).

Class of traffic	Flexible type of foundation, miles	Rigid type of foundation, miles
Class I	42[1]	34
Class IIA	106[2]	72
Class II	280	58[3]
Class III and IV	220	48[3]
Totals each type	648	212

Grand total 860 miles.

[1] Mileage on which it is desirable to change foundation type 5 per cent of total.

[2] Mileage in the doubtful class 12 per cent of total.

Total mileage on which there is some justificaion for changing type 17 per cent of total constr ucted.

[3] Suitability of original design doubtful.

ANALYSIS OF DIVISION 7 (TYPE SELECTION POLICY)

To illustrate definitely the importance of general policy in reconstruction, we will analyze Division 7, N. Y. State Highway Department. There is considerable unthinking popular demand and some tendency on the part of the Highway Department to favor change of type from the existing flexible form to rigid pavements even on fairly light traffic roads. The problem for this division can be stated as follows. We have at present approximately 7,700,000 sq. yd. of pavement which will have to be either resurfaced or reconstructed within the next 10 to 15 years. Of this amount, 5,800,000 sq. yd. are flexible base pavements. These pavements can be made adequately strong either by resurfacing, adding additional macadam depth, or by reconstruction to a rigid type of foundation. After adequate strength is attained by either method, the future surface maintenance cost for any specified surface is about the same. Approximately 30 per cent of flexible base pavements can be made adequate in strength with a resurfacing depth of 2 to 3 in. Approximately 70 per cent will require a reinforcing middle course in addition to a new surface course. The average difference in construction cost between retention of foundation type with necessary reinforcing and surface improvement as compared with change of type lies between $1.00 to $1.20 per square yard. If we adopt the policy of change of foundation type, the necessary reconstruction will cost approximately $6,000,000 more than the policy of retention and strengthening existing foundations with surface improvement. For the first 10 years, the maintenance charge will be less for the change of foundation type policy and might amount to an extreme maximum difference of $0.03 per square yard per year although $0.02 is probably nearer right. After the 10-year period, the future surface maintenance and renewal charge will be about the same for both policies. The difference in maintenance for the first 10 years will not exceed $0.03 $\times$ 5,800,000 $\times$ 10 or $1,800,000 which means a net saving for the retention of type policy of $4,000,000 in this district alone. Any final rational solution will, of course, be a combination of the two policies. Policy in regard to taxation for maintenance and renewal is crystallizing along the lines that traffic must pay for the upkeep and renewal of the state system roads. It makes no difference whether this is done by a gasoline tax or a vehicle license tax, the fact remains that the motorists are going to foot the bills and it is about time that the organized automobile interests took an active intelligent interest in reconstruction policy and efficient maintenance. At the present time, many auto club officials advocate the change of type policy because they dislike surface oiling maintenance and do not realize that foundation type has nothing to do with this trouble and also because they have been led to believe by non-technical propoganda that the difference in maintenance costs of the two methods is greater than is

actually the case. They do not realize that in adopting this attitude, they are merely sandbagging their own interests. Up to date, they have spent most of their energy combatting reasonable traffic regulation and direct vehicle taxation which has been the main cause of the shortage in necessary funds which has put our system in bad shape. Motorists naturally object to the surface oiling nuisance of macadam surfaces on main roads but after a macadam base is resurfaced with either asphaltic concrete or a block surface, this annoying feature is eliminated at a much lower cost than by complete change of foundation type.

The application of the general policy of utilization of base is illustrated by an official report on page 479.

Effect of Delay in Reconstruction on Final Cost.—The costly result of delay in resurfacing at the proper time is shown by the following official report.

Apr. 9, 1923

Mr.————————,
Division Engineer,
Rochester, N. Y.

Dear Sir:

Find attached design report for the proposed Federal Aid Reconstruction of Monroe Ave., Road 94, Sta. 129 + 27 to 219 + 80.4 (1.71 miles).

Two estimates have been made. Design 1 calls for an 18-ft. width of Cement Concrete Pavement 8 by 6½ by 8 in. thick, Mesh and Bar Reinforcement with special shoulders 3 ft. wide on both sides, constructed of the old macadam excavated from the center of the road. Design 1 is estimated to cost $78,000.

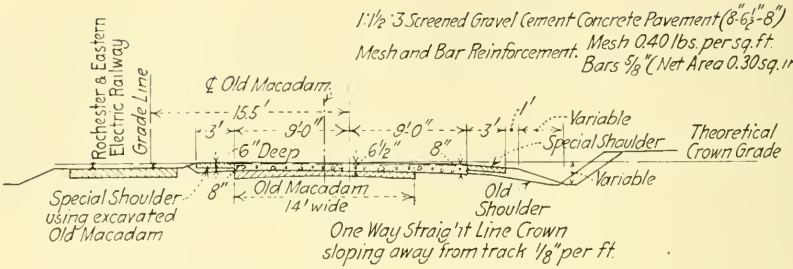
Design 2 calls for an 18-ft. Concrete Pavement 7 by 6½ by 8 in. thick with 2-ft. width of gutter and a curb 7 in. high along the left side of the pavement, Sta. 129 to 184 where the Rochester and Eastern Electric Ry. tracks are located close to the pavement edge. A special shoulder 3 ft. wide constructed of excavated macadam is used on the right side. From Sta. 184 to 219 the design remains the same as for the first case. This design gives an effective pavement width of 20 ft. Sta. 129 to 184 and provides a raised curb protection next to the track. Design 2 is estimated to cost $88,000.

Detail Report

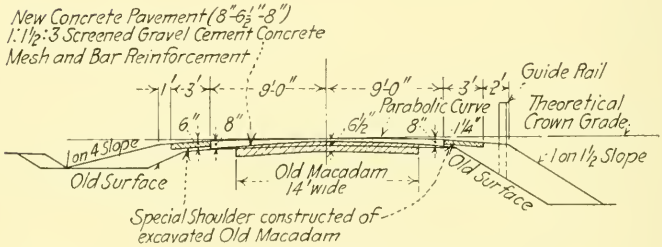
Location and Length.—The proposed reconstruction extends from Clover St. to the end of the Brick Pavement near the Barge Canal (Sta. 129 + 27 to 219 + 80.4) a distance of 1.71 miles of which 0.12 miles is in the town of Brighton and 1.59 miles in the town of Pittsford. This proposed reconstruction covers the portion of Monroe Ave. which is at present in poor condition. The balance of Road 94 between Rochester and Pittsford is in very fair shape for traffic.

Previous Designs and Recommended Treatment.—The portion of Road 94 covered by this contract has needed attention since 1918. In 1920 a survey was made and two alternate designs submitted. The recommended design of 1920 provided for widening the old 14-ft. macadam to 16 ft. with a slag macadam extension and a new surface course of 2-in. depth of Topeka Mix on a 1½-in. average depth of Binder evener course. Slag macadam shoulders were provided on both sides of the pavement (3 ft. wide) giving a total width of hard surface of 22 ft. This design was estimated to cost $50,000. An alternate design was prepared but not recommended using 6-in. Uniform Depth of Cement Concrete 16 ft. wide at an estimated cost of $60,000.

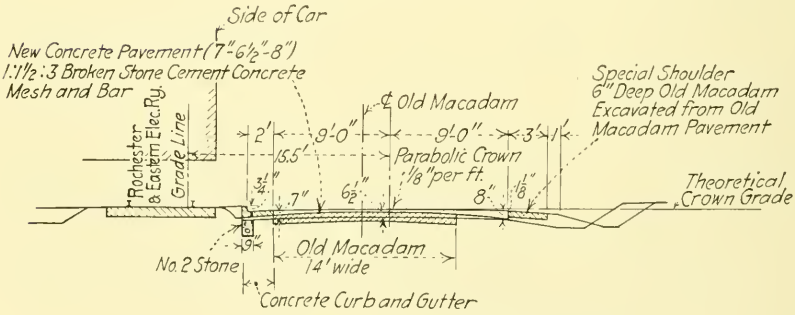
At the time these estimates were made (1920) the old macadam was firm but rough and the additional 3½ in. should have provided the additional strength needed to prevent deterioration under the growing volume and weight of traffic. During the last 3 years



Alternate Design Sta. 129 to 184.



Recommended Design Sta. 184 to 219.



Recommended Design Sta. 129 to 184.

FIG. 167.—Recommended and alternate designs reconstruction road 94 (1923 design—estimated costs $88,000 and $78,000).

however, the value of the old macadam as a base course, has been greatly reduced, as the lack of the additional 3½ in. proposed, has permitted churning under heavy loads which would not have occurred had the pavement been strengthened at the proper time. This loss of effectiveness due to breaking of the bond makes it advisable to eliminate consideration of the use of the old macadam as a base for an Asphaltic Concrete Top, and makes it desirable to construct some kind of a rigid pavement. Considering limitation of funds Cement Concrete is probably a reasonable solution for this contract.

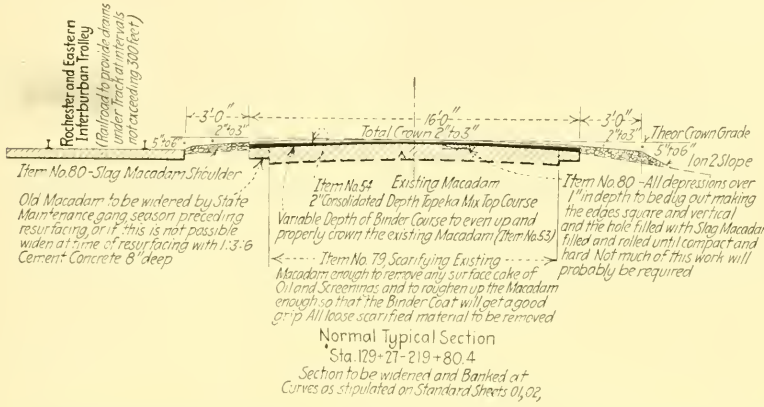

Rochester and Eastern Interburban Trolley
(Railroad to provide drains under Track at intervals not exceeding 300 feet)
3'0"
2"to3"
16'0"
Total Crown 2"to3"
3'0"
2"to3"
Theor Crown Grade
5"to6"
1on2 Slope
Item No 80-Slag Macadam Shoulder
Old Macadam to be widened by State Maintenance gang season preceding resurfacing or if this is not possible widen at time of resurfacing with 1:3:6 Cement Concrete 8" deep
Item No 54 Existing Macadam
2" Consolidated Depth Topeka Mix Top Course
Variable Depth of Binder Course to even up and properly crown the existing Macadam (Item No 53)
Item No 79 Scarifying Existing Macadam enough to remove any surface cake of Oil and Screenings and to roughen up the Macadam enough so that the Binder Coat will get a good grip All loose scarified material to be removed
Item No 80 -All depressions over 1" in depth to be dug out making the edges square and vertical and the hole filled with Slag Macadam, filled and rolled until compact and hard Not much of this work will probably be required
Normal Typical Section
Sta 129+27-219+80.4
Section to be widened and Banked at Curves as stipulated on Standard Sheets 01, 02

FIG. 168A.—Recommended design reconstruction road 94 (1920 design estimated cost $50,000).

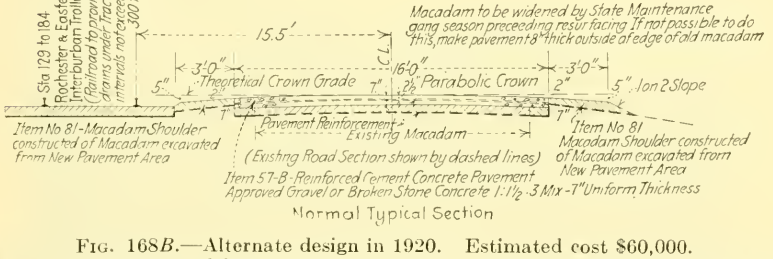

Sta 129 to 184
Rochester & Eastern Interburban Trolley
(Railroad to provide drains under Track at intervals not exceeding 300 feet)
Macadam to be widened by State Maintenance gang season preceding resurfacing If not possible to do this, make pavement 8" thick outside of edge of old macadam
15.5'
7"
3'0"
16'0"
3'0"
5"
Theoretical Crown Grade
7"
2½" Parabolic Crown
2"
5"
1on2 Slope
Item No 81-Macadam Shoulder constructed of Macadam excavated from New Pavement Area
Pavement Reinforcement
Existing Macadam
(Existing Road Section shown by dashed lines)
Item No 81 Macadam Shoulder constructed of Macadam excavated from New Pavement Area
Item 57-B-Reinforced Cement Concrete Pavement Approved Gravel or Broken Stone Concrete 1:1½:3 Mix-7" Uniform Thickness
Normal Typical Section

FIG. 168B.—Alternate design in 1920. Estimated cost $60,000.

Note.—A comparison of figures 167 and 168 shows the effect of delay in reconstruction cost due to serious deterioration of old macadam.

The only way we can get any practical value of the old macadam, is to drop the new pavement into the old road and use the excavated macadam for shoulders close to the concrete. This is the general basis of the present design.

It can be readily seen that the delay in reconstruction due to shortage of funds has greatly increased the cost of the necessary work.

Recommended Section.—The chief problem in the design is the matter of drainage along the car tracks, Sta. 129 to 184. The best method of treatment is Design 2 with the Curb and Catch Basin Construction. If curb is not used, J. E. Kelly has made the excellent suggestion of using a one-way crown away from the track, which will help in the matter of surface water seepage under the left edge, but will not entirely eliminate this trouble. On account of this seepage and the poor character of the soil on the outer edge of the old shoulder, we recommend an edge depth of 8 in. for Design 1. The center gets some benefit from the old macadam and less seepage softening, and a 6½ in. is recommended. For Design 2 we recommend an 8-in. edge depth where no gutter is used and a 7-in. edge depth where gutter is constructed. The center depth is the same as for Design 1. Excavated macadam is to be used for the new shoulder next to the concrete.

Culverts.—The existing culverts on this road are the old style Vitrified Clay Pipe and are as a rule, in poor condition. New Cast-iron Pipe has been designed.

There are two old masonry structures which should be pointed up, given new footing courses and lengthened by the Town of Pittsford.

The Rochester and Eastern Electric Ry. should be required to provide the necessary outlet structures under their tracks to take care of the large flow at culvert locations, and to handle small ditch flow at intervals of not exceeding 300 ft.

Alignment and Grade.—The alignment is excellent. Sharpest curve 5°. No new right of way will be required.

The grades are easy 5 per cent Maximum.

The grade line as laid will provide enough excavated old macadam for the new proposed special stone shoulders. For the new earth shoulder widening both Borrow and Overhaul will be required.

Borrow.—Borrow can be obtained from the Barge Canal Spoil banks within 2,000 ft. of Sta. 219, or from the Old Tow Path of the Old Erie Canal west of lock 62. The first source is the more feasible and has been used in computing overhaul.

Materials.—*Stone and Sand* must be imported delivery (West Shore Ry. Pittsford) 1,000 ft. from Sta. 220 of this contract.

Water Lake Ontario Water Company. Hydrant at Sta. 136 and new proposed Long Meadow Pipe Line, Sta. 190 to 219.

Cement Pittsford Delivery (West Shore Ry.).

(Signed)
W. G. HARGER
Designer.

FIG. 169.—Small brick cube resurfacing on macadam base on steep grade.

Suitable Surfaces.—The suitability of surfaces has been thoroughly discussed in Chap. II and III. The same conclusions hold namely that for Class III and IV traffic waterbound macadam oiled or gravel well maintained by dragging and oiling are satisfactory under all conditions. These surfaces are satisfactory on any steep grade occurring on improved road systems. For Class II traffic Waterbound, Penetration Bituminous

Macadam, Asphaltic Concretes, Cement Concrete and any standard block or small cube is satisfactory. The limitations of use on account of grade has been discussed (see pages 151 and 152). Standard-sized paving brick, asphalt block, etc. are not as rational as the smaller units on a flexible base and they also increase the difficulties of shoulder work.

For Class I, any standard type of high-grade surface is suitable under the same limitations of local preference and final cost discussed in Chap. II. At the present time, the most easily used type for Class I resurfacing is some type of asphaltic concrete but on steep grades this is not very satisfactory and we hope that the brick or stone people will produce a satisfactory smaller unit sized block for these conditions. On main roads, it is desirable to use a surface which is not maintained by surface oiling as the oiling process is disagreeable for traffic for a short period each season. On secondary roads, short-time annoyance of surface oiling is far outweighed by the reduced total cost of the macadam type. That is, very few communities can afford perfection of comfort on secondary highways.

RECONSTRUCTION DESIGN

General Principles of Design.—Each road is a special problem requiring a complete knowledge of the strength of the existing pavement and careful alternate estimates of different methods of treatment. There are an innumerable number of solutions which serve the purpose provided the general basic principles are not violated. A few typical examples are given to illustrate common cases. The basic principles of reconstruction design are listed as follows:

1. Make all necessary alignment changes on the score of safety or reasonable maximum grades (see official report, page 477).
2. Adequate pavement width is essential and should be provided at this stage of programs.
3. Retain same general type of foundation unless existing pavement is practically worthless.
4. Strength design for either the macadam or rigid type is determined in the manner discussed in Chap. II. High-type surface should never be used on a weak base. This is often done.
5. Suitability of surface depends on traffic demands. On heavy-traffic roads, avoid a surface which requires oiling.
6. Retain same type of surface where existing pavements are to be widened only.
7. Avoid use of so-called dual types unless unusual conditions such as central car tracks prevail.
8. Safe and solid shoulders are essential.
9. Avoid deep, dangerous ditches. Use storm sewer systems if possible to eliminate dangerous ditches.

Utilization of Old Macadam or Gravel.—An old macadam pavement must never be scarified unless the loosened material is entirely removed and used for shoulder material on the side of the new surfacing. Scarified macadam never can be put back into a good hard lock as the mechanical bond of the larger stone fragments is broken and they are completely separated by the screenings. Scarified macadam is nothing but a stone gravel which cannot have the stability of the interlock construction. Inequalities and shape of crown must be corrected by adding new material.

If an old macadam pavement is to be widened and used as a base for a high type surface, the widening should be done by state maintenance forces a year before the resurfacing to give it a chance to harden under traffic. If the widening and new high grade surface must be constructed hurriedly the most feasible solution is to use 1:3:6 concrete about 8 in. deep for the foundation widening in place of macadam although this method is not advised nor is it often necessary with reasonable forethought. If an old macadam is to be widened and recapped with macadam on Class II or III roads, all the work may be done the same season although it is desirable to complete the widening well in advance of the new top and give it considerable traffic pounding to better the consolidation.

If an old macadam pavement must be strengthened before being recapped with a high-grade asphaltic concrete or block surface, the resurfacing additional thickness of macadam must be constructed a year ahead of the final resurfacing to give it a chance to harden under traffic. *Asphaltic concretes or block surfaces must never be laid on new macadam which has not been pounded by traffic for at least* 6 *months.*

All pot holes must be dug out at least 3 in. deep, the *edges squared up,* filled with 1¼ to 2½-in. stone or slag, thoroughly rolled, filled with slag or stone screenings and well compacted. Cold patch should not be used for work of this kind. *Pot holes must never be filled by varying the depth of the macadam overlying course.*

The reinforcing middle course must not be laid until all pot holes are completely repaired. This course must be fairly uniform in thickness; there should be no sudden variation of over 20 per cent in finished depth.

The top course must be *very uniform in thickness.* Macadam top should have no sudden variation of more than 15 per cent, and asphaltic concrete surface mix no sudden variation of more than 10 per cent in depth. Violation of these rules in regard to uniformity of depth occur quite frequently and explain many unsatisfactory repair jobs.

Case 1. Widening Existing Pavements.—This case is illustrated by Figs. 170 to 172 Road 5 near Rochester, N. Y. carrying 4,000 to 5,000 vehicles daily (10-hour count in summer). This road is an asphaltic concrete (modified Topeka) on concrete base Sta. 0 to 74 and an Amiesite Top on Macadam Base Sta. 74 to 130. The foundation soil is sand and

gravel. It has served traffic well with the exception of width. Figure 171 shows the first design prepared which violated all the basic principles

FIG. 170*A*.—Typical conditions Road 5, Sta. 0 to 74 (asphaltic concrete on cement concrete base).

FIG. 170*B*.—Typical conditions Road 5, Sta. 74 to 110 (amiesite on macadam base).

of reconstruction design. It changed general type of foundation and used different types of surfacing. Figure 172 shows a new design which not only retains type but is cheaper in construction cost. Figure 172

is a satisfactory design for a case of this kind with the exception that the concrete base should be thicker than shown (for recommended depths, see Table 23, page 137). The object of the undercut concrete base connection is to prevent separation of additional base from original base; it gives a good grip contact.

CASE 2. RECAPPING A WORN-OUT RIGID BASE PAVEMENT HAVING A REMOVABLE TOP

Essential Points.—This case is very simple; it merely involves the removal of the old worn-out surface and its replacement by any standard

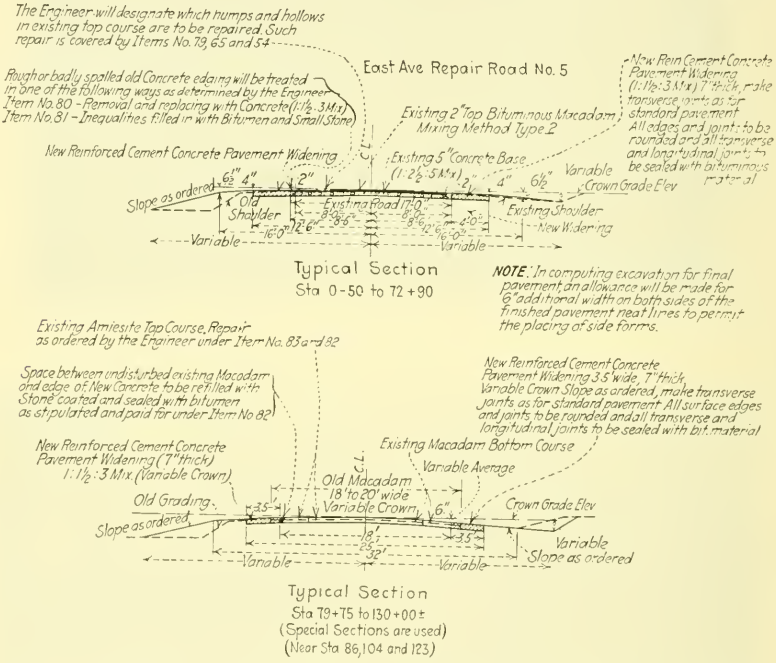

The Engineer will designate which humps and hollows in existing top course are to be repaired. Such repair is covered by Items No. 79, 65 and 54
East Ave. Repair Road No. 5
Rough or badly spalled old Concrete edging will be treated in one of the following ways as determined by the Engineer
Item No. 80 - Removal and replacing with Concrete (1:1½:3 Mix)
Item No. 81 - Inequalities Filled in with Bituminous and Small Stone
Existing 2" Top Bituminous Macadam Mixing Method Type 2
New Reinforced Cement Concrete Pavement Widening
Existing 5" Concrete Base (1:2½:5 Mix)
Slope as ordered
Old Shoulder
Existing Road No. 2
Existing Shoulder
New Widening
Variable
Crown Grade Elev
Typical Section
Sta 0-50 to 72+90
NOTE. In computing excavation for final pavement an allowance will be made for 6" additional width on both sides of the finished pavement neat lines to permit the placing of side forms.
Existing Amiesite Top Course, Repair as ordered by the Engineer under Item No. 83 and 82
Space between undisturbed existing Macadam and edge of New Concrete to be refilled with Stone coated and sealed with bitumen as stipulated and paid for under Item No. 82
New Reinforced Cement Concrete Pavement Widening (7" thick) 1:1½:3 Mix (Variable Crown)
Old Grading
Existing Macadam Bottom Course
Variable Average
Old Macadam 18' to 20' wide Variable Crown
Typical Section
Sta 79+75 to 130+00±
(Special Sections are used)
(Near Sta 86, 104 and 123)

FIG. 171.—Design 1, Road 5, this design violates all principles of reconstruction.

type of surface desired. The old rigid base is retained and repaired if necessary. New edging or stone shoulders bound with bitumen are provided. This case does not require illustration by typical sections.

CASE 3. RECAPPING A WORN-OUT MONOLITHIC TYPE RIGID PAVEMENT OF AMPLE STRENGTH AND WIDTH

Essential Points.—Broken down or weak areas of the old pavement are cut out and removed and the edges of the retained pavement squared up. The subgrade is undercut along connecting edge similar to Fig. 173; new concrete base is laid and well tamped into the undercut. This concrete is protected from traffic and allowed to set 14 days before the new

surface is placed. Two general types of surface can be used, Asphaltic Concretes or any standard block or cube form of pavement.

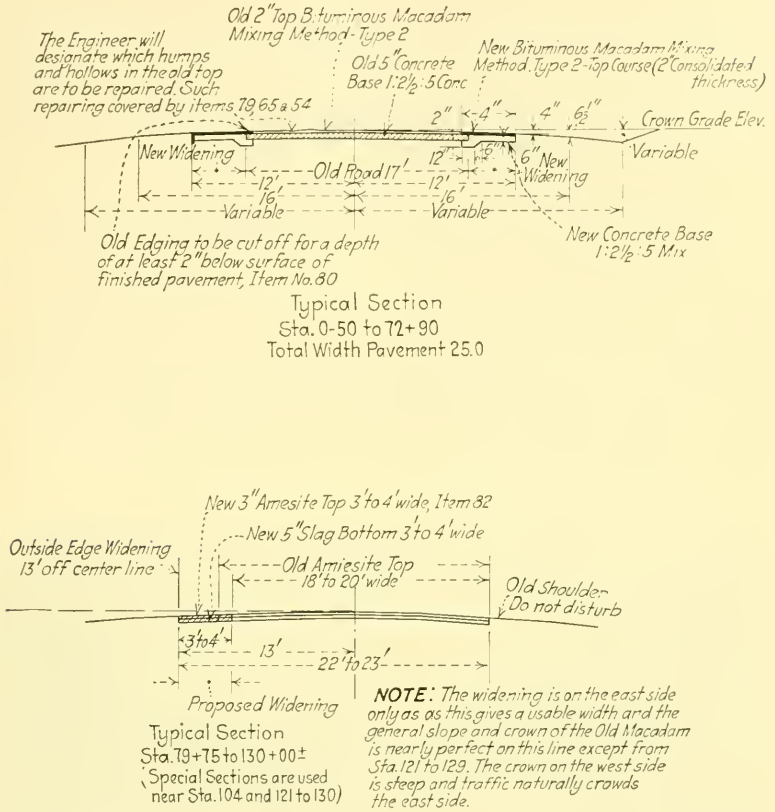

Old 2"Top Bituminous Macadam Mixing Method-Type 2
The Engineer will designate which humps and hollows in the old top are to be repaired. Such repairing covered by items 79, 65 & 54
Old 5"Concrete Base 1:2½:5 Conc
New Bituminous Macadam Mixing Method. Type 2-Top Course (2"Consolidated thickness)
2"
4"
4"
6½"
Crown Grade Elev.
New Widening
Old Road 17'
12'
12'
16'
Variable
12"
6"
6" New Widening
16'
Variable
Variable
Old Edging to be cut off for a depth of at least 2" below surface of finished pavement, Item No. 80
New Concrete Base 1:2½:5 Mix
Typical Section
Sta. 0-50 to 72+90
Total Width Pavement 25.0
New 3"Amesite Top 3'to 4'wide, Item 82
New 5"Slag Bottom 3'to 4'wide
Outside Edge Widening 13'off center line
Old Amiesite Top
18'to 20'wide
Old Shoulder-Do not disturb
3'to4'
13'
22'To 23'
Proposed Widening
Typical Section
Sta. 79+75 to 130+00±
(Special Sections are used near Sta. 104 and 121 to 130)
NOTE: The widening is on the east side only as as this gives a usable width and the general slope and crown of the Old Macadam is nearly perfect on this line except from Sta. 121 to 129. The crown on the west side is steep and traffic naturally crowds the east side.

FIG. 172.—Design 2, Road 5, this design complies with basic design principles and is cheaper than design 1.

If Asphaltic Concrete is used, the procedure is essentially as follows: Pot holes in the old pavement over ½ in. deep but not too deep to weaken the base are chiselled out to a square edge and filled with coarse stone cold patch material filled with coarse sand and thoroughly rolled. Small depressions, cracks and crown irregularities are cleaned out and filled by varying the depth of regular binder course. For this purpose, an average depth of 1 to 1½ in. compacted binder is generally sufficient. The final surfacing can be constructed of any desired mix of Asphaltic Concrete ranging in depth from 1½ to 2½ in. as desired. For Class II or IIA Traffic, 1½-in. modified Topeka makes a good surface; for Class I traffic 2 in. of fine aggregate Sheet Asphalt makes a good surface. *The thickness of the surface course must be uniform* (*see page* 466). Well com-

pacted bituminous macadam shoulders at least 4 to 6 in. deep and 2 ft. wide should be constructed along the edge to prevent excessive edge wear of the high-class pavement. Safe width of grading shoulder and safe ditch section should be provided. This case is illustrated by Fig. 173.

If a standard block surface is used, the repair of the base for weak areas is the same as described. Pot hole repair for depressions over ½ in. deep consists of chiselling out to a square edge and filling with 1:2:4 or

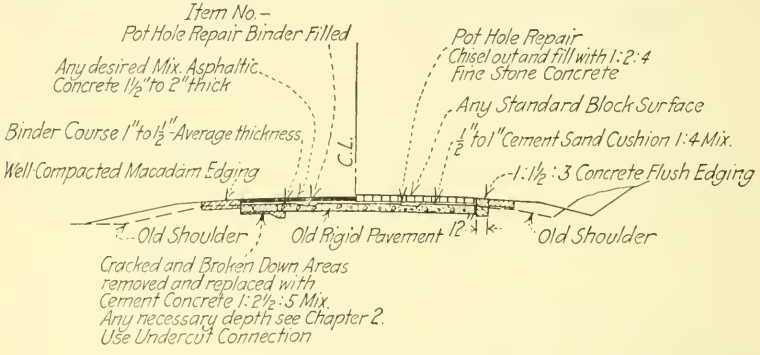

Item No.–
Pot Hole Repair Binder Filled
Any desired Mix. Asphaltic Concrete 1½" to 2" thick
Binder Course 1" to 1½" Average thickness
Well Compacted Macadam Edging
C.L.
Pot Hole Repair
Chisel out and fill with 1:2:4 Fine Stone Concrete
Any Standard Block Surface
½" to 1" Cement Sand Cushion 1:4 Mix.
1:1½:3 Concrete Flush Edging
Old Shoulder
Old Rigid Pavement 12"
Old Shoulder
Cracked and Broken Down Areas removed and replaced with Cement Concrete 1:2½:5 Mix. Any necessary depth see Chapter 2. Use Undercut Connection

Fig. 173.—Typical design, Case 3.

1:½:3 concrete which is protected and allowed to set for 14 days. Cracks, minor irregularities of crown and small depressions are cleaned out and removed by varying the depth of the cement sand cushion on which the new surfacing is to be laid. An allowance of 1- to 1½-in. average depth of 1 to 4 cement sand cushion is generally ample to meet this requirement. On this cement sand cushion, the block surface is constructed in the same manner as for original construction. The edge of the pavement should be protected by a simple concrete flush edging outside of which the stone shoulder, earth grading and ditch section are the same as for the previous case. This case is illustrated by Fig. 173.

CASE 4. CHANGE OF TYPE ON CLASS I TRAFFIC ROAD

(*a*) Where Old Macadam is of Ample Width

Essential Points.—Drop new rigid pavement below surface of old rough macadam in order to get a uniform supporting surface and in order to obtain cheaply the stone shoulder needed on each side of the new rigid pavement. That is, the old macadam top course is scarified and removed and used as a shoulder along the sides of the new pavement.

The new pavement should be of ample depth for macadam support conditions, see Chap. II on Design for the effect of macadam underlying support.

(*b*) Where Old Macadam is of Less Width Than New Pavement

The same procedure applies in regard to scarifying, removing old top and utilizing it for new shoulder. In designing depth, it is good policy to increase edge depth over middle depth where the advantage of macadam support is lost. It is poor design to attempt to widen the macadam

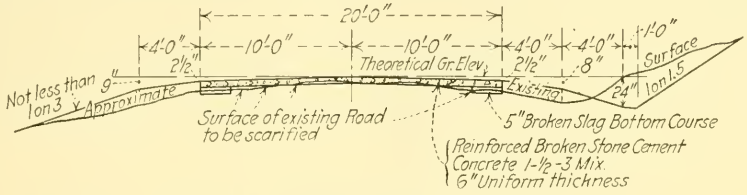


Fig. 174.—Case 4, Example of poor design.

(*a*) New pavement too thin for Class I traffic.
(*b*) New pavement should have been dropped into existing macadam utilizing scarified top course for shoulders.
(*c*) New pavement should have been thickened outside of old macadam instead of constructing a narrow subcourse of 5 ft. broken slag.

Fig. 175.—Three strip dual type. This is popular as it segregates traffic but it is an expensive road to maintain and is not recommended for any extensive mileage. Mixed types are fundamentally poor practice.

and then use uniform depth of new pavement (see also Chap. II for relation of edge to center depth).

Figure 174 illustrates poor practice. Figure 167 illustrates good practice. Figure 46, page 123, shows an 18-ft. concrete surfacing job in New York State with central joint.

CASE 5. THREE-STRIP DUAL TYPE OF CONSTRUCTION. CLASS I TRAFFIC

(Not recommended)

The general idea of this type of reconstruction is shown in Fig. 175. This type is fundamentally wrong and is expensive to maintain although it is quite popular with traffic as it tends to separate the lines of travel.

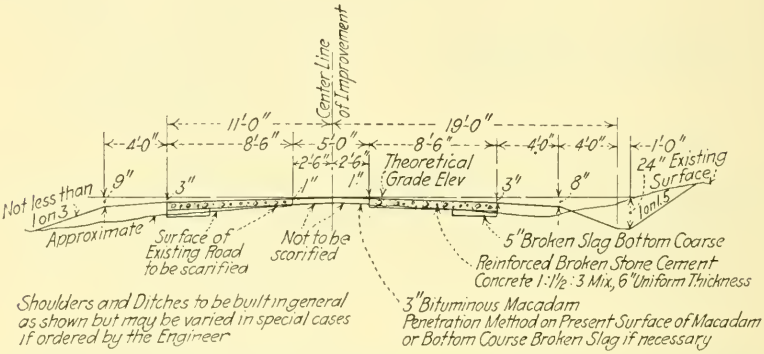


FIG. 176.—Case 5. Dual type (poor practice).

(*a*) New pavement too thin for Class I Traffic.
(*b*) New pavement should have been thickened at edge instead of constructing subbase course of 5 in. broken slag.
(*c*) Stone or gravel shoulders should have been provided outside of rigid pavement.

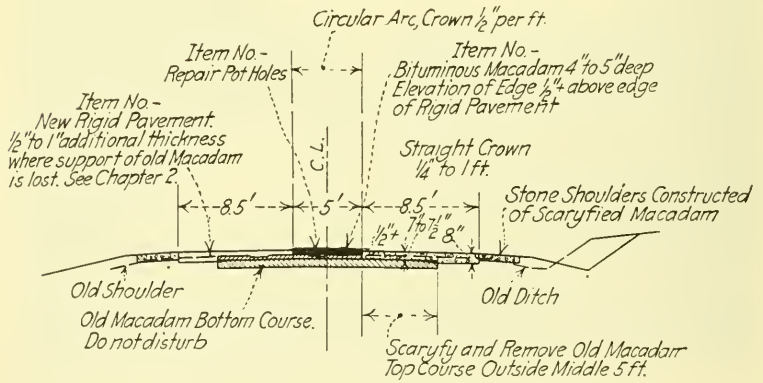

Circular Arc, Crown ½" per ft.
Item No. - Repair Pot Holes
Item No. - Bituminous Macadam 4" to 5" deep Elevation of Edge ½" + above edge of Rigid Pavement
Item No. - New Rigid Pavement. ½" to 1" additional thickness where support of old Macadam is lost. See Chapter 2.
C. L.
Straight Crown ¼" to 1 ft.
8.5'
5'
8.5'
Stone Shoulders Constructed of Scaryfied Macadam
7" to 8"
½" +
Old Shoulder
Old Ditch
Old Macadam Bottom Course. Do not disturb
Scaryfy and Remove Old Macadam Top Course Outside Middle 5 ft.

FIG. 176A.—Case 5 (good practice).*

Essential Points.—The same principles of utilizing old macadam top course for shoulder material applies as in Case 4; the same principle of deepening the pavement along the edges where it loses macadam support applies as in Case 4. Case 5 is illustrated by Fig. 176 (Poor Practice), 176A (Good Practice).

* NOTE.—Where dual type is used on new grading the concret strip should be uniform in depth as the corners are all exterior classification (see Chap. II, pp. 116–120).

CASE 6. RECAPPING FIRM ROUGH MACADAM

Essential Points.—Pot holes in the surface over ½ in. deep are picked out for the full depth of the top course and the edges squared up. The hole is filled with regular top stone or slag (1¼- to 2½-in. size) thoroughly rolled to a tight lock; filled with coarse sand or screenings and hard rolled. The surface course is then laid in the usual manner using any type desired. Waterbound or Penetration Bituminous Macadam 3-in. consolidated depth can be used for Class III traffic. Penetration bituminous 3 in. deep is satisfactory for Class II traffic. Some form of asphaltic concrete preferably of the coarse aggregate type averaging 2½ to 3 in. finished

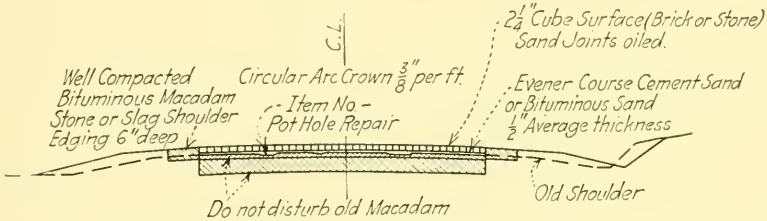


FIG. 177A.—Recapping old firm macadam with cube surface.

depth is satisfactory for Class II or IIA. Coarse graded amiesite is particularly adapted to such cases as it adds materially to the structural strength of the old base. Under the heavier IIA traffic, a 1-in. binder course with 1½ to 2 in. of modified Topeka is a good solution provided steep grades are not encountered. *The thickness of the top course must be uniform.* On steep grades, the single pour bituminous macadam or small cubical block surface is used. If a block or cube surface is used the minor surface irregularities of the old macadam remaining after the pot holes have been repaired are eliminated by a varying depth of 1:4 cement sand cushion; joints are filled with either bitumen or sand with a light surface oiling. The new shoulders should be a good gravelly soil and the grading width of new shoulders and ditches must be safe.

Don'ts.—In recapping an old firm rough macadam, do not scarify the old surface and add material (see page 466). If the old surface is a smooth slippery flush coat bituminous macadam on which it is difficult to get a good grip for the surface coat, it can be either scarified and completely removed and used on the shoulder or a 3½-in. depth of new top can be used which has considerable internal stability of its own or a bituminous paint binder can be applied, overlaid with an open mix binder about 1 in. deep and finished off with a Modified Topeka Surface mix.

Don't attempt to widen an old macadam base the same year that it is recapped with a high grade asphaltic concrete or block surface Class IIA or I traffic. Widening for this class of work should be done the preceding year. Under Class II or III traffic with an ordinary macadam

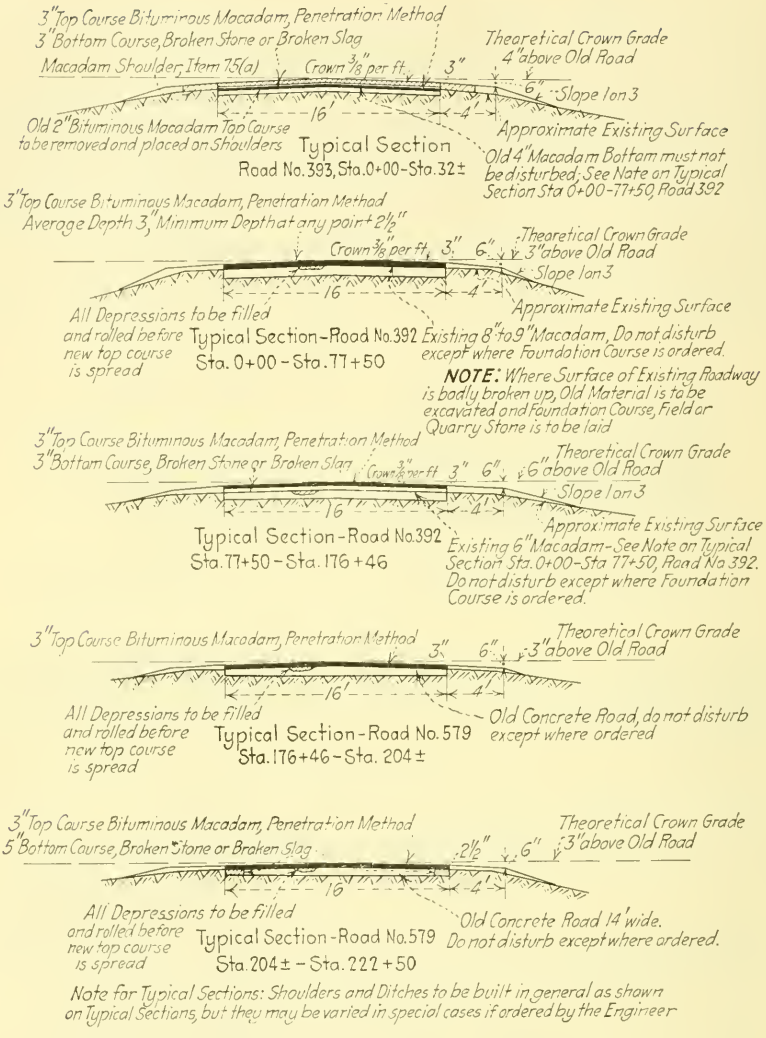

3" Top Course Bituminous Macadam, Penetration Method
3" Bottom Course, Broken Stone or Broken Slag
Macadam Shoulder, Item 75(a)
Crown 3/8" per ft.
Theoretical Crown Grade 4" above Old Road
Slope 1 on 3
Old 2" Bituminous Macadam Top Course to be removed and placed on Shoulders
Typical Section
Road No. 393, Sta. 0+00 - Sta. 32±
Approximate Existing Surface
Old 4" Macadam Bottom must not be disturbed; See Note on Typical Section Sta 0+00-77+50, Road 392
3" Top Course Bituminous Macadam, Penetration Method
Average Depth 3", Minimum Depth at any point 2 1/2"
Theoretical Crown Grade 3" above Old Road
All Depressions to be filled and rolled before new top course is spread
Typical Section - Road No. 392
Sta. 0+00 - Sta. 77+50
Existing 8" to 9" Macadam, Do not disturb except where Foundation Course is ordered.
NOTE: Where Surface of Existing Roadway is badly broken up, Old Material is to be excavated and Foundation Course, Field or Quarry Stone is to be laid
3" Top Course Bituminous Macadam, Penetration Method
3" Bottom Course, Broken Stone or Broken Slag
Theoretical Crown Grade 6" above Old Road
Typical Section - Road No. 392
Sta. 77+50 - Sta. 176+46
Approximate Existing Surface
Existing 6" Macadam - See Note on Typical Section Sta. 0+00-Sta 77+50, Road No 392. Do not disturb except where Foundation Course is ordered.
3" Top Course Bituminous Macadam, Penetration Method
Theoretical Crown Grade 3" above Old Road
All Depressions to be filled and rolled before new top course is spread
Typical Section - Road No. 579
Sta. 176+46 - Sta. 204±
Old Concrete Road, do not disturb except where ordered
3" Top Course Bituminous Macadam, Penetration Method
5" Bottom Course, Broken Stone or Broken Slag
Theoretical Crown Grade 3" above Old Road
All Depressions to be filled and rolled before new top course is spread
Typical Section - Road No. 579
Sta. 204± - Sta. 222+50
Old Concrete Road 14' wide. Do not disturb except where ordered.
Note for Typical Sections: Shoulders and Ditches to be built in general as shown on Typical Sections, but they may be varied in special cases if ordered by the Engineer

Fig. 177*B*.—Illustrating good current practice. Cases 6 and 7.

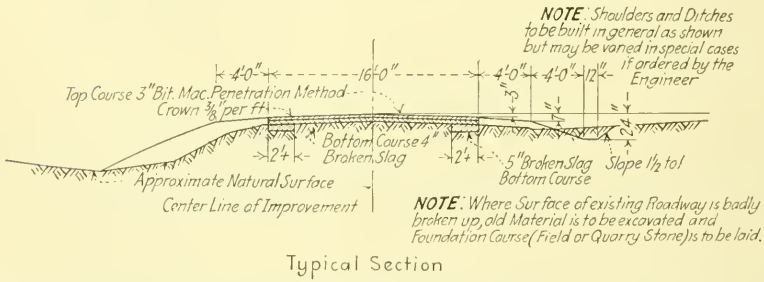

NOTE: Shoulders and Ditches to be built in general as shown but may be varied in special cases if ordered by the Engineer
Top Course 3" Bit. Mac. Penetration Method
Crown 3/8" per ft.
Bottom Course 4" Broken Slag
5" Broken Slag Bottom Course
Slope 1/2 to 1
Approximate Natural Surface
Center Line of Improvement
NOTE: Where Surface of existing Roadway is badly broken up, old Material is to be excavated and Foundation Course (Field or Quarry Stone) is to be laid.
Typical Section

Fig. 178.—Case 7. Good typical example of widening, strengthening and recapping an old narrow weak macadam pavement. Division 7, New York State.

recapping, this restriction does not hold. If a quick widening is absolutely necessary Class I or IIA traffic, a depth of 8 in. of 1:3:6 cement concrete for the additional foundation width is probably the best solution.

The final top course must be uniform in thickness (see page 466).

CASE 7. REINFORCING AND RESURFACING AN OLD WEAK MACADAM CLASS IIA, II OR III TRAFFIC

Essential Points.—Actual conditions as to underlying soil and existing depth of macadam must be thoroughly investigated by test holes and records of spring blow ups. The portions of the road which are entirely inadequate should be completely removed and rebuilt to the proper depth (see Chap. II, page 100). For this work, regular construction methods apply utilizing any available type of subbase or foundation course. Where a middle reinforcing course of 3- to 5-in. depth in conjunction with the new surface course will produce an adequate depth, the old road is left untouched. Pot holes are repaired as in Case 6. These must be repaired before the reinforcing course is laid. The reinforcing course is essentially the same as ordinary macadam bottom and ordinary construction methods and material requirements apply. The top course construction is the same as for new construction where Waterbound or Penetration Macadam is used. If a high-grade asphaltic concrete or block surface is contemplated under Class IIA traffic, it must not be laid the same season as the reinforcing course. Traffic must be permitted on the reinforcing course for at least one year. Under these conditions the reinforcing course should be bound with screenings instead of sand and ravelling prevented by applications of Calcium Chloride. Case 7 is illustrated by Figs. 177 and 178.

TYPICAL REPORT ILLUSTRATING THE ADVANTAGE OF RECONSTRUCTION RELOCATIONS

Rochester, N. Y.
May 16, 1923.

Mr. ————————
Division Engineer
Rochester, N. Y.

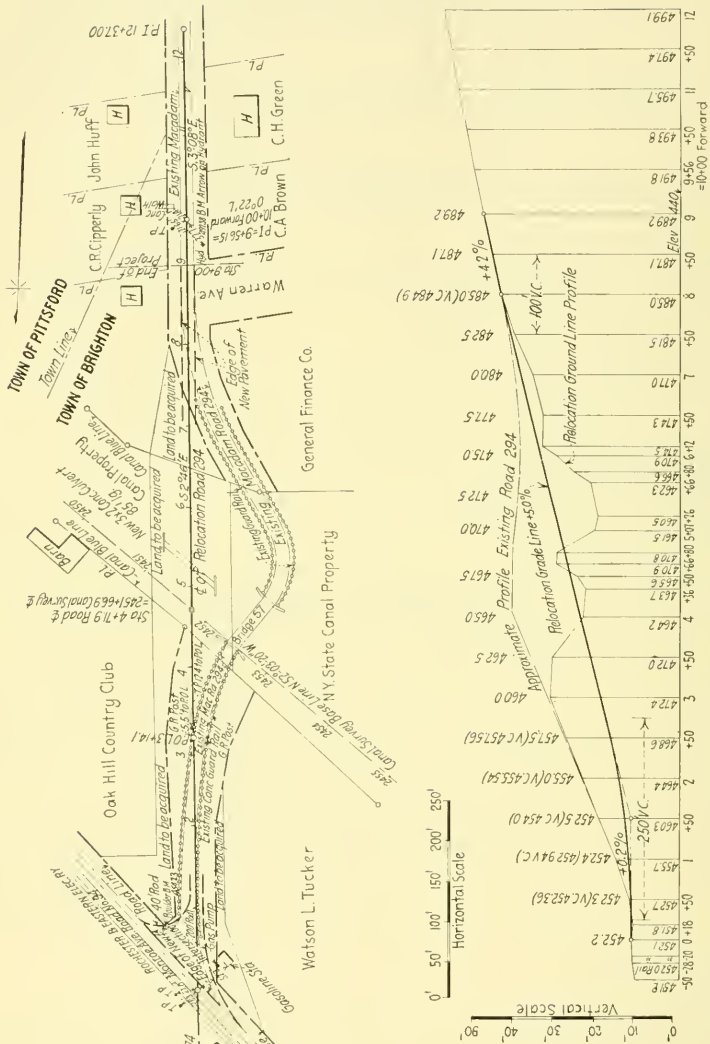
Dear Sir:

Find attached detail report on the proposed relocation of Clover St. Road No. 294 Sta. 0 to 9 (Canal Crossing).

We recommend a 16 ft. bituminous macadam pavement on straight alignment with 5 per cent maximum grade at an estimated cost of $9,500. If cement concrete pavement is used the cost is estimated at $11,800.

This relocation is justified on the score of safety alone as it eliminates two sharp curves, an 8 per cent grade and an old narrow unsafe bridge. The reduction in motor operation cost on the new line probably warrants a construction expenditure of about $10,000 but this consideration need not be given much weight for this particular project although it furnishes an additional argument in favor of the work.

Sincerely yours,
W. G. Harger,
Designer.



Plan and profile to accompany official report illustrating the value of the Clover Street relocation.

DETAIL REPORT

Clover Street Road 294 (Canal Crossing)

1. Location and Length.—The proposed relocation extends from Monroe Ave. Road No. 94 to Sta. 9 + 00 of Clover Street Road 294 a distance of 900 ft.

2. Traffic Classification.—Road 294 is on the verge between Class II and Class III traffic. The 1920 census gives 550 vehicles in 12 hours summer travel and the 1922 census 400 vehicles in 12 hours. For purposes of estimating the economic value of the proposed improvement an allowance of 800 vehicles daily will be made.

3. Grades and Alignment.—The proposed relocation materially improves the grade and alignment. The existing alignment has two sharp curves one of 75-ft. radius and one of 200 ft. radius. The existing grades are steep, an 8 per cent bridge approach grade is the maximum. The proposed alignment is straight with a 5 per cent maximum rate of grade. The distance on the new line is 44 ft. shorter than on the existing road and the old narrow unsafe bridge over the abandoned Erie Canal is replaced by a permanent fill with culvert drainage. The cost of the necessary grading on the new location is estimated at $4,000. The economic benefit of this grading is estimated at $10,000 (see following tabulation based on curve No. 1, Fig. 5, page 16).

TABULATION OF CAPITALIZED MOTOR OPERATION COSTS

Old and New Locations (Sta. 0 to 12 + 00)

Rate of grade, per cent	Estimated capitalized cost motor operation 100 vehicles daily per foot of distance	Old profile		New profile	
		Distance	Amount	Distance	Amount
1 or less	$ 9.10	80	$ 728	50	$ 455
2.0	9.15	320	2,928		
2.6	9.21	.....	.....	200	1,842
3.0	9.25	100	925		
3.4	9.31	.....	.....	100	931
3.9	9.37	.....	.....	100	937
4.0	9.40	80	752		
4.2	9.46	300	2,838	156	1,475
5.0	9.70	.....	.....	550	5,335
8.0	12.50	320	4,000		
Totals.....	.....	1,200	$12,171	1,156	$10,975

Net capitalized advantage of new line per 100 vehicles daily—$1,200.

Net advantage 800 vehicles daily—$9,600 say $10,000.

4. Suitable Pavement Types (Based on Traffic Classification).—This road is Class II traffic (see Section 2 of this report). For this volume and character of traffic either bituminous macadam or cement concrete will serve satisfactorily. For the special conditions prevailing it is probable that bituminous macadam is the more rational type to choose based on the following facts. This relocation is a short piece of road No. 294 which is a bituminous macadam construction; it connects at the north end (Sta. 0) with the road No. 474 which is bituminous macadam and with road No. 94 which is bituminous macadam to the west and will be reinforced cement concrete to the eastward. This relocation will have some deep fills which will probably settle for two or three years after construction which is not a favorable condition for rigid pavement construction. The existing macadam

on the old road can be excavated and reused for subbase course of the new macadam construction which gives a distinct economic advantage to the use of this type.

For record purposes comparative estimates have been prepared for both bituminous macadam and cement concrete.

5. Soils.—The subgrade soil is a medium clay comparatively free from ground water seepage.

6. Uniform Strength Design.

Sta. to Sta.	Soil	Grading conditions	Total pavements depths*	
			Macadam	Concrete
0–2	Medium clay	Cut and shallow fills	16	7
2–7	Medium clay	Fills over 3 in. deep	11	7
7–9	Medium clay	Cut and shallow fills	16	7

* These depths are based on Table 17, page 100, for the macadam design and on the minimum allowable depth concrete pavements, page 255.

As a further evidence of proper allowable depth of macadam on this road the existing macadam (10 in. deep) is in perfect shape on the high fill Sta. 0 to 5 after 10 years use. At no point on road No. 294 has there been any evidence of weakness where the old macadam is 16 in. deep in cuts. This old road carries a regular milk collecting truck route and this evidence extending over ten years seems to strengthen the conclusions expressed by Table 17, page 100.

We recommend for the macadam construction a 3 in. depth of top course; 4 in. depth of new stone or slag middle course and from 4 to 9 in. of reused old macadam for the foundation course.

7. Materials Required (Pavement Estimate).—There are 1,900 sq. yd. of pavement on this job. The macadam type of pavement will require: 320 cu. yd. foundation course (4 to 9 in. thick); 200 cu. yd. middle course (4 in. thick); 160 cu. yd. top course (3 in. thick); 4,300 gal. of bituminous binder.

The concrete type of pavement will require: 360 cu. yd. concrete 1:1½:3 mix (6⅔ in. thick); 700 bbl. cement; 17,200 sq. ft. mesh reinforcement (40 lb. per 100 sq. ft.); 7,000 lb. bar reinforcement; 400 lin. ft expansion joints.

8. Materials Available.—The only local material available is the existing macadam Sta. 0 to 9 which can be excavated and reused for foundation course macadam construction. Three hundred and fifty cubic yards of this old macadam is available for reuse.

All other materials must be imported. Cement (Pittsford delivery). Stone (Pittsford delivery or truck from Rochester). Sand (Pittsford delivery or truck from Rochester). Bitumen (Pittsford delivery or Tarvia from Brighton). Water (hydrant supply Sta. 0 and Sta. 9. Lake Ontario Water Company).

9. Comparative Estimates (see Table 30, page 392).

Type of pavement	Average thickness	Costs per sq. yd. of pavement				
		Est. const. cost	Yearly interest	Yearly maintainance	Yearly renewal	Total yearly charge
Bituminous macadam.....	13	$2.10	$0.105	$0.035	$0.11	$0.25
Cement concrete.....	7	3.20	0.160	0.010	0.12	0.29

Grading, culverts and incidentals are estimated at approximately $4,900.

The total cost including all items with an allowance of approximately $800 for Engineering, Inspection and contingence is as follows:

Bituminous Macadam	$ 9,500
Cement Concrete	11,809

10. Maximum Allowable Expenditure and Final Recommendations.—Any necessary expenditure is allowable on this project on the score of safety as outlined in the first paragraph of the report. The economic advantage of the new location due to better grades and shorter distance probably warrants a construction expenditure of about $10,900 to $11,000 (see Section 3 of this report). The new pavement does not reduce motor operation costs appreciably as the present pavement is equivalent to a first class asphaltic concrete surface as far as operation is concerned. The total economic value of the proposed work does not probably exceed $11,000 to $12,000.

Either cement concrete or bituminous macadam could be constructed without loss to the community but the selection of bituminous macadam seems the better business investment in this particular case as discussed in Section 4 of this report.

Signed,
W. G. Harger,
Designer.

TYPICAL REPORT ILLUSTRATING THE EFFECT OF ULTILIZATION OF OLD MACADAM ON RECONSTRUCTION COSTS

Rochester, N. Y.
April 10, 1923.

Mr. ————————
Division Engineer
Rochester, N. Y.

Dear Sir:

Find below summarized design report on the reconstruction of Road No. 99, State route No. 30, Class IIA traffic, from Sta. 89 to 239 + 35, a distance of 2.83 miles.

We recommend an entirely new cement concrete pavement 7 in. average depth Sta. 89 to 132. From Sta. 132 to 239 we recommend that the old macadam (at present ranging in depth from 8 to 11 in. as determined by 50 test holes) be retained as a base course, widened to 18 ft. with gravel foundation course, the thickness of the old road increased by the addition of a 4 in. slag waterbound middle course which is to be used by traffic at least 3 months and then capped with 3 in. of some type of asphalt concrete preferably Amiesite or Topeka. This design is estimated to cost $134,000. If cement concrete is used for the entire distance the estimated cost is $146,000. These two designs are practically equal from the standpoint of maintenance and motor operation costs.

An alignment change is made between Sta. 109 and 114; this change in alignment is amply justified on the score of safety regardless of the increased cost. It increases the cost over following the old road about $11,000 but it probably cheapens the cost of motor operation enough to warrant a construction expenditure of at least $6,000 even if the increased safety is given no weight in the decision.

Sincerely yours,
W. G. Harger,
Designer.

CHAPTER V

MINOR POINTS OF DESIGN

For convenience of reference this chapter gives a few illustrations of current practice in connection with incidental features of road construction such as guide rail, retaining walls, curbs, sidewalks, cobble ditch protection, guide and danger signs, snow fence, etc. This data is per-

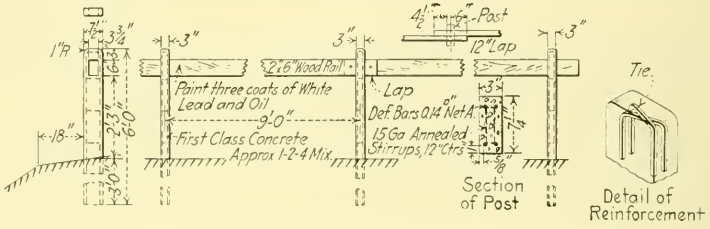


FIG. 179.—Concrete-wooden guide rail (New York State 1922). This type is a warning rail only.

haps out of place in a book of this character but incidental information is useful in emergencies and gives the student some idea of current practice in minor details.

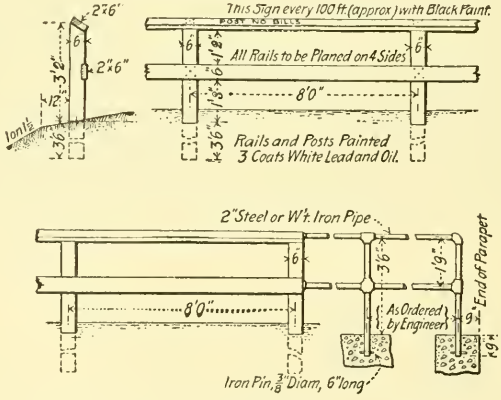

This Sign every 100 ft. (approx.) with Black Paint.
All Rails to be Planed on 4 Sides
8'0"
Rails and Posts Painted 3 Coats White Lead and Oil.
2"x6"
2"x6"
2"Steel or Wt. Iron Pipe
As Ordered by Engineer
End of Parapet
Iron Pin, 3/8" Diam, 6" long

FIG. 180.—Wooden guide rail (New York State 1921). This type is a warning rail only.

Guard Rail.—Guard rail serves two purposes, to warn and to protect. If protection is essential at really dangerous points a solid retaining wall is desirable. Most types of so called guard rail serve more in the nature of a warning than as an actual protection. Wooden structures require

continual maintenance and for this reason concrete posts, rail and steel cable have been used on the score of reducing the necessity of continual repair. Figures 179 to 184 show usual types.

Retaining Walls.—In unusual cases retaining walls are needed in road construction. Plain or reinforced concrete walls are generally used,

FIG. 181.—Typical wooden guide rail.

the selection depending upon the relative cost. The plain concrete wall is considered the best type for heights up to 12 ft.; the reinforced cantilever form from 12 to 18 ft. and above 18 ft. the buttressed design.

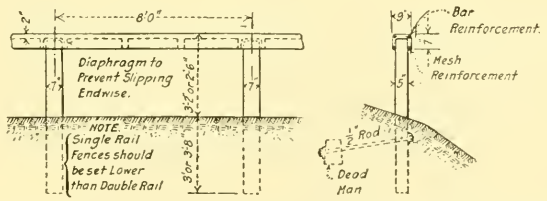


FIG. 182.—Typical reinforced concrete rail with post anchor blocks. This type gives some real protection as well as acting as a warning.

Standard Practice for the plain and reinforced cantilever types follow. The necessity for walls higher than 18 ft. is very rare. For the design of buttressed walls the reader is referred to the standard works of reinforced concrete.

Retaining walls are usually built in monolithic sections of 20 to 25 ft. in length; expansion joints are provided between these sections. The expansion joints may consist simply of a plane of weakness between the

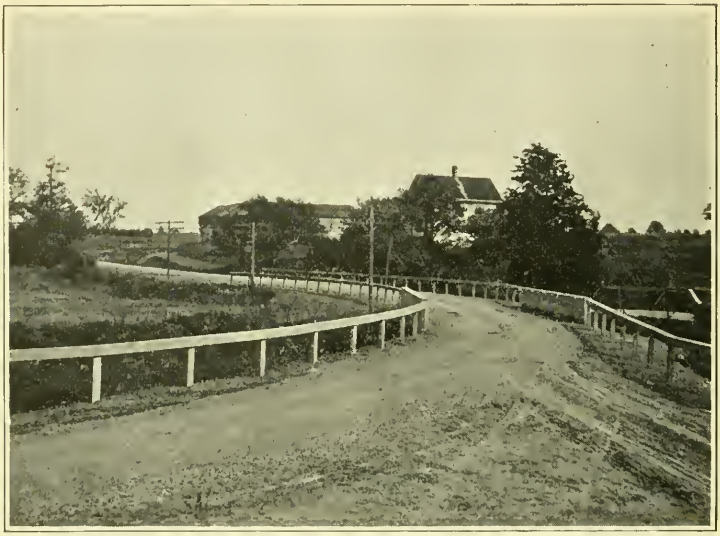


FIG. 183.—Photograph of rail shown in Fig. 182.

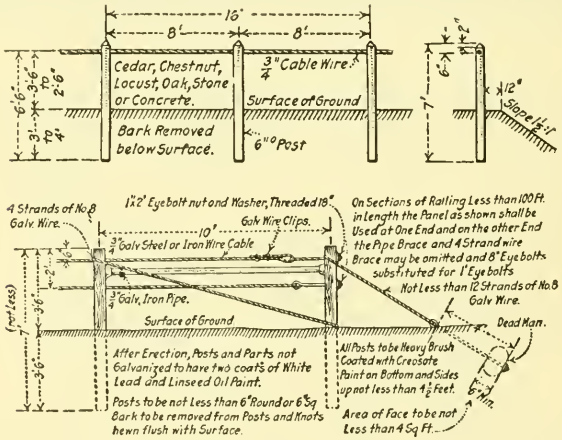
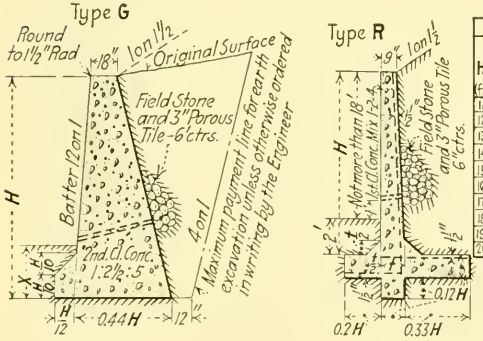

15'
8'
8'
Cedar, Chestnut, Locust, Oak, Stone or Concrete.
3/4" Cable Wire.
Surface of Ground
Bark Removed below Surface.
6"ø Post
6'-6"
3'-6"
2'-6"
3'-4"
6'-6"
7'
1:2
Slope 1½:1
4 Strands of No. 8 Galv. Wire.
1"x2" Eyebolt nut and Washer, Threaded 18"
Galv. Wire Clips.
10'
3/4" Galv. Steel or Iron Wire Cable
3/4" Galv. Iron Pipe.
Surface of Ground
On Sections of Railing Less than 100 Ft. in Length the Panel as shown shall be Used at One End and on the other End the Pipe Brace and 4 Strand wire Brace may be omitted and 8" Eyebolts substituted for 1' Eyebolts
Not Less than 12 Strands of No. 8 Galv. Wire.
Dead Man.
All Posts to be Heavy Brush Coated with Creosote Paint on Bottom and Sides up not less than 1½ Feet.
After Erection, Posts and Parts not Galvanized to have two coats of White Lead and Linseed Oil Paint.
Posts to be not Less than 6" Round or 6" Sq.
Bark to be removed from Posts and Knots hewn flush with Surface.
Area of Face to be not Less than 4 Sq. Ft.

FIG. 184.—Cable guard rail. This type gives some protection.

sections produced by allowing one section to set before building the adjacent wall, or it may be a key joint as shown in Fig. 188 and the plane of separation may be made more pronounced by coating the concrete with a thin layer of asphaltum or pitch.

FIG. 185.—Example of high class retaining wall and guard wall. This is a real protection.



H (ft)	Reinforced Concrete Wall (Type R) Reinforced Steel Bars of Deformed Section — Stem * Net Area	Stem * Spacing c to c	Stem * Length	Heel Net Area	Heel Spacing c to c	Heel Length	Toe Net Area	Toe Spacing c to c	Toe Length
11	0.60	6¼"	12'-2"	0.44	7½"	4'-11½"	0.44	9½"	3'-3½"
12	0.60	5½"	13'-3½"	0.44	6¼"	5'-5½"	0.44	8¼"	3'-8"
13	0.60	5"	14'-5"	0.44	5¼"	6'-0"	0.44	7¼"	4'-0½"
14	0.60	4½"	15'-6½"	0.60	6¼"	6'-6"	0.60	8½"	4'-4½"
15	0.60	4"	16'-8"	0.60	5⅜"	7'-0"	0.60	7⅜"	4'-9"
16	1.00	6"	17'-9"	0.60	4¾"	7'-6½"	0.60	6½"	5'-1½"
17	1.00	5½"	18'-10½"	0.78	5½"	8'-0½"	0.78	7⅝"	5'-6"
18	1.00	5"	20'-0"	0.78	4⅞"	8'-7"	0.78	6⅞"	5'-10½"
19	1.00	4½"	21'-1½"	0.78	4⅜"	9'-1"	0.78	6¼"	6'-2½"
20	1.00	4⅛"	22'-3"	0.78	4"	9'-7"	0.78	5¾"	6'-7"

* In each set of 3 bars in stem, the first bar which is of the length given, extends to top of wall; the second bar extends to height ⅔ H, and the third bar extends to height ⅓ H

When "Type G" wall is used below the roadway as a sustaining wall, the height "H" shall not exceed 13' and the distance "X" shall not be less than 3' except where the foundation is rock or entirely below frost.

When "Type G" wall is used above the roadway as a bank wall the height "H" shall not exceed 20' and the distance "X" shall not be less than 2' for heights less than 10' and not less than 0.2 H for heights greater than 10'.

FIG. 186.—New York State retaining walls.

REINFORCING STEEL BARS OF DEFORMED SECTION (FIG 186)

	Stem[1]			Heel			Toe		
H, feet	Net area	Spacing c. to c., inches	Length, feet and inches	Net area	Spacing c. to c., inches	Length, feet and inches	Net area	Spacing c. to c., inches	Length, feet and inches
11	0.601	6¼	12– 2	0.442	7½	4–11½	0.442	9½	3– 3½
12	0.601	5½	13– 3½	0.442	6¼	5– 5½	0.442	8¼	3– 8
13	0.601	5	14– 5	0.442	5¼	6– 0	0.442	7¼	4– 0½
14	0.601	4½	15– 6½	0.601	6¼	6– 6	0.601	8½	4– 4½
15	0.601	4	16– 8	0.601	5⅜	7– 0	0.601	7⅜	4– 9
16	0.994	6	17– 9	0.601	4¾	7– 6½	0.601	6½	5– 1½
17	0.994	5½	18–10½	0.785	5½	8– 0½	0.785	7⅝	5– 6
18	0.994	5	20– 0	0.785	4⅞	8– 7	0.785	6⅞	5–10½
19	0.994	4½	21– 1½	0.785	4⅜	9– 1	0.785	6¼	6– 2½
20	0.994	4⅛	22– 3	0.785	4	9– 7	0.785	5¾	6– 7

[1] In each set of 3 bars in stem, first bar which is of length given, extends to top of wall, second bar to height $\frac{2}{3}H$, third bar to height $\frac{1}{3}H$.

When Type *W* is used as a bank wall (that is, above the roadway), max. $H = 20$ ft.; min. $X = 2$ ft. for H of 5 to 10 ft.; and $0.2H$ for H greater than 10 ft.

When Type *W* is used as a sustaining wall (that is, below the roadway), max. $H = 13$ ft.; and min. $X = 3$ ft., except where foundation is rock or entirely below frost.

When Type *R* is used as a bank wall, max. $H = 20$ ft.; min. $X = 0.15H$ for H greater than 10 ft.

When Type *R* is used as a sustaining wall, max. $H = 13$ ft.; min. $X = 0.25H$ for H greater than 10 ft.

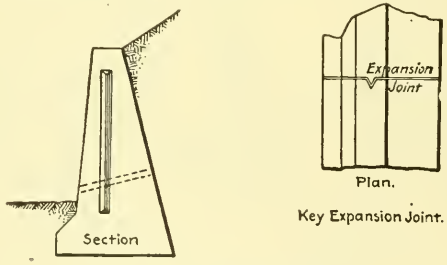


FIG. 187.—Key joints.

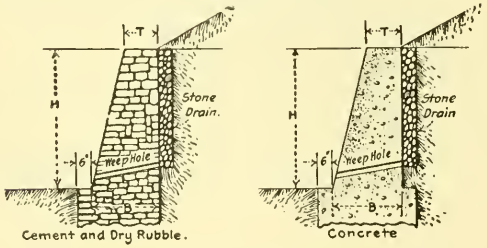


FIG. 188.—Pennsylvania retaining walls.

RETAINING WALLS, STATE OF PENNSYLVANIA (FIG. 188)

Cement masonry						Dry rubble masonry						Concrete masonry					
Ground level with top of wall			Surcharged			Ground level with top of wall			Surcharged			Ground level with top of wall			Surcharged		
H	*T*	*B*	*H*	*T*	*B*	*H*	*T*	*B*	*H*	*T*	*B*	*H*	*T*	*B*	*H*	*T*	*B*
4–0	1–6	1– 8	4–0	2–0	2– 3	4–0	2–0	2–0	4–0	2–0	2– 7	4–0	1–6	1– 6	4–0	1–6	2– 0
5–0	2–0	2– 0	5–0	2–0	2–10	5–0	2–0	2–6	5–0	2–0	3– 4	5–0	1–6	1– 9	5–0	1–6	2– 5
6–0	2–0	2– 5	6–0	2–0	3– 5	6–0	2–0	3–0	6–0	2–0	4– 0	6–0	1–6	2– 2	6–0	1–6	2–10
7–0	2–0	2–10	7–0	2–0	3–10	7–0	2–0	3–6	7–0	2–0	4– 7	7–0	1–6	2– 5	7–0	1–6	3– 5
8–0	2–0	3– 3	8–0	2–0	4– 6	8–0	2–0	4–0	8–0	2–0	5– 4	8–0	1–6	2–10	8–0	1–6	3–10
9–0	2–0	3– 7	9–0	2–0	5– 0	9–0	2–0	4–6	9–0	2–0	5–10	9–0	1–6	3– 2	9–0	1–6	4– 4
10–0	2–0	4– 0	10–0	2–0	5– 7	10–0	2–0	5–0	10–0	2–0	6– 7	10–0	1–6	3– 6	10–0	1–6	4–10

Cement Masonry.—Top of wall not less than 1 ft. 6 in., 2 ft. 0 in. if possible. Face battered; back perpend cular. Weep holes with blind drain in wet localities.

Dry Rubble.—Top of wall not less than 2 ft. 0 in. Face battered; back perpendicular. Courses perpendicular to face batter. Face of wall pointed. Weep holes with blind drain in wet localities.

Concrete.—Top of wall not less than 1 ft. 6 in. Face battered 1:12; back battered or stepped. Weep holes with blind drain in wet localities. Expansion joints every 25 ft. 0 in.

All offsets 6 in. Bottom of footing below frost line. (Depth of footing at least 3 ft.). Backfilling done with acceptable material placed in layers of not less than 6 in. and thoroughly rammed.

FIG. 189.—Temporary timber cribbing to hold side hill fill (Pioneer roads).

Repointing Masonry and Refacing Old Walls.—Old masonry structures can often be used complete or in part by repointing the joints; they should be cleaned out thoroughly with a chisel and filled flush with a 1:1 Portland cement mortar.

The author does not believe in facing up old masonry abutments or walls if it can be avoided; however, if it seems advisable, because of

shortage of funds, the old joints should be well cleaned out and hook dowels used as shown in Fig. 190. One dowel every 6 sq. ft. is good practice.

The concrete facing should be at least 12 in. thick, have a good footing course and be reinforced to prevent settlement and temperature cracks.

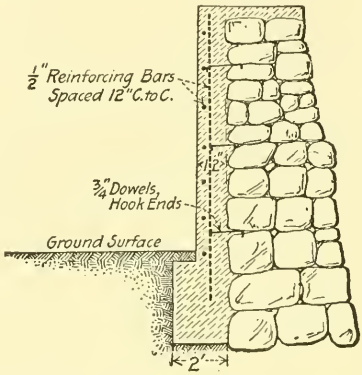


Fig. 190.—Facing old masonry.

Toe Walls.—Toe walls are nothing more than low retaining walls or very substantial curbs. They are used in cuts on the outside of the gutters to prevent unstable side slopes from filling the gutters or heaving them out of shape by sliding pressure. Figure 191 gives a section of Eden Valley Hill near Buffalo, N. Y. where a clay quicksand cut was successfully protected in this manner.

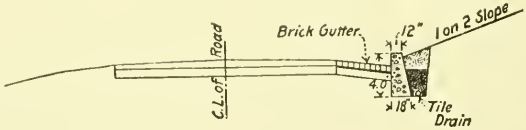


Fig. 191.—Typical toe wall.

Curbs.—Curbs are constructed of stone and of concrete.

Stone Curbs.—The cuts given show the methods of setting; the size of curbstones for first-class work range from 16 to 22 in. in depth, 5 to 6 in. in thickness and 3 to 5 ft. in length. For small villages, curbstone of 4 in. width set in the simplest manner shown, is satisfactory. The stones most used are granites, bluestones of New York State, and the tougher sandstones such as Medina, Berea, Kettle River, etc. The prices range widely, depending on the locality of the work.

Curb Radii.—A good radius for drives is 4 ft. For right-angle Main Street intersections 13 ft. For acute or abtuse angles 10 to 20 ft. Figure 193 shows a satisfactory sidewalk corner layout used in Rochester, N. Y.

Cobble Gutters, Brick Gutters, Ditch Linings, Etc.—Cobble gutters are used to protect the ditches from wash on steep grades and at entrances to intersecting roads where there is not sufficient headroom for a culvert.

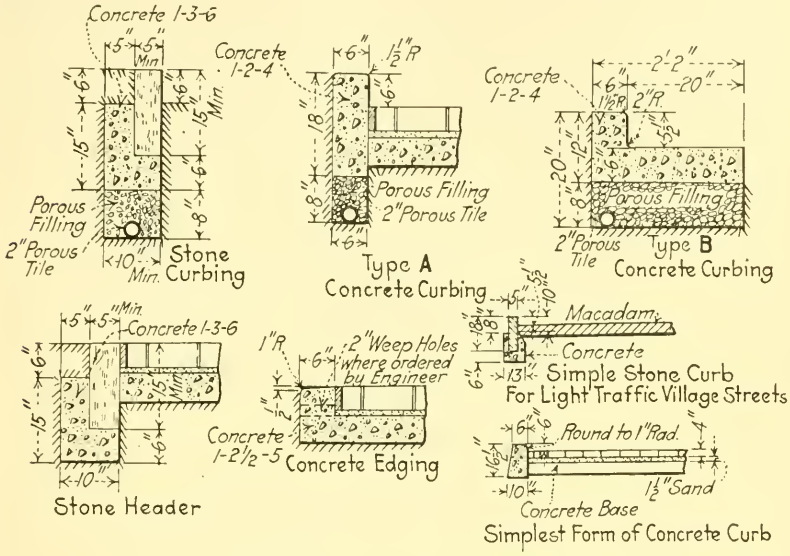


FIG. 192.—Typical curb details.

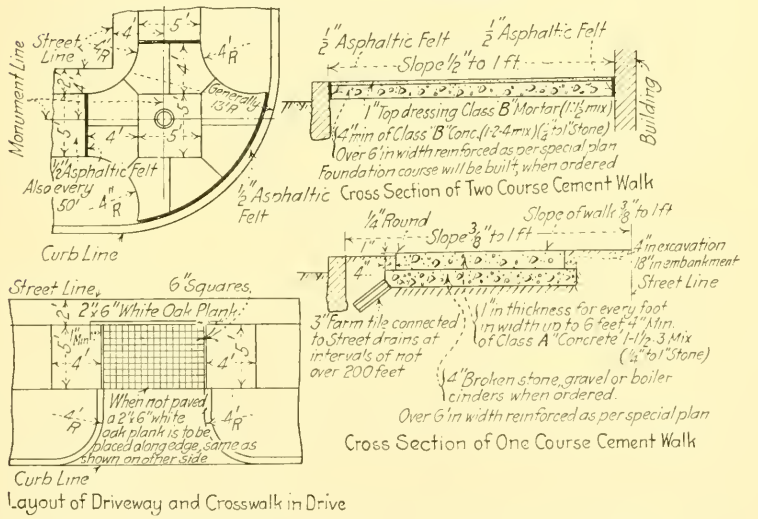

Monument Line
Street Line
Curb Line
½"Asphaltic Felt
Also every 50'
Generally 13'R
Slope ½"to 1 ft
1"Top dressing Class B"Mortar(1:1½ mix)
4"min of Class B"Conc.(1-2-4 mix)(¼"to1"Stone)
Over 6'in width reinforced as per special plan
Foundation course will be built when ordered
Cross Section of Two Course Cement Walk
Building
Slope of walk ⅜"to 1 ft
¼"Round
Slope ⅜"to 1 ft
4"in excavation
8"in embankment
Street Line
3"Farm tile connected to Street drains at intervals of not over 200 feet
1"in thickness for every foot in width up to 6 feet 4"Min. of Class A"Concrete 1-1½-3 Mix (¼"to1"Stone)
4"Broken stone, gravel or boiler cinders when ordered.
Over 6'in width reinforced as per special plan
Cross Section of One Course Cement Walk
6"Squares
2"6"White Oak Plank
When not paved a 2"6"white oak plank is to be placed along edge, same as shown on other side
Layout of Driveway and Crosswalk in Drive

FIG. 193.—Typical sidewalk detail and curb corner layout (Rochester, N. Y.).

Also at the entrances to private property where the grade line of the ditch might be badly cut by vehicles.

Where cobblestones are not available, ordinary building brick may be used or No. 4 crushed stone as shown in Fig. 194.

Catch Basins.—Figure 195 shows ordinary rural highway catch basins and drop inlets. Figure 196*A* shows a satisfactory curb inlet city or village catch basin. Catch basins are to be avoided on rural highways if possible as the grate tends to clog and cause ponding. Where they are necessary some clear opening not entirely covered by the grate should be provided.

Guide and Danger Signs.—Signs add to the convenience and safety of travel. Good examples of Standard Practice are shown in Figs. 198

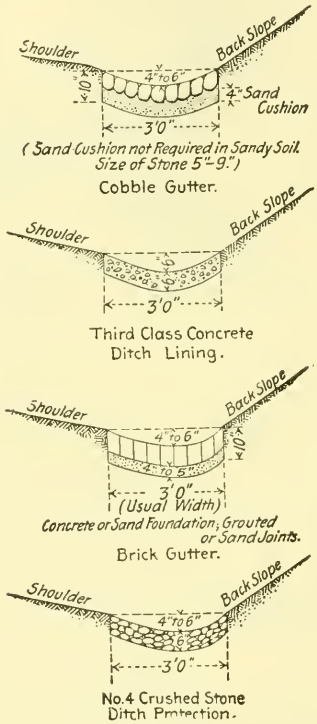


Fig. 194.—Typical ditch protections.

and 199. The indiscriminate use of danger signs is inadvisable. Their use should be confined to actual danger conditions and they should be placed so that headlights at night will show them up in ample time.

Trolley Track and Crossing Details.—Figure 200 gives the essentials of elevation, clearance and construction details where tracks are an integral part of the pavement design. The standard shown is the New Jersey Practice.

Monuments.—Figure 196*F* Miscellaneous Standards gives good practice in the matter of Permanent Street Monuments. The same type of marker 6 in. above ground makes a good road right-of-way marker.

Cattle Guards.—In western territory ranch owners will often grant road right-of-ways for a nominal sum but stipulate that the right-of-way shall not be fenced as it would cut off part of their range from water. The boundaries of these ranges are generally fenced and where the road passes this fence a gate must be used to prevent straying of cattle; it is more or less of a nuisance for every user of the road to open and close the

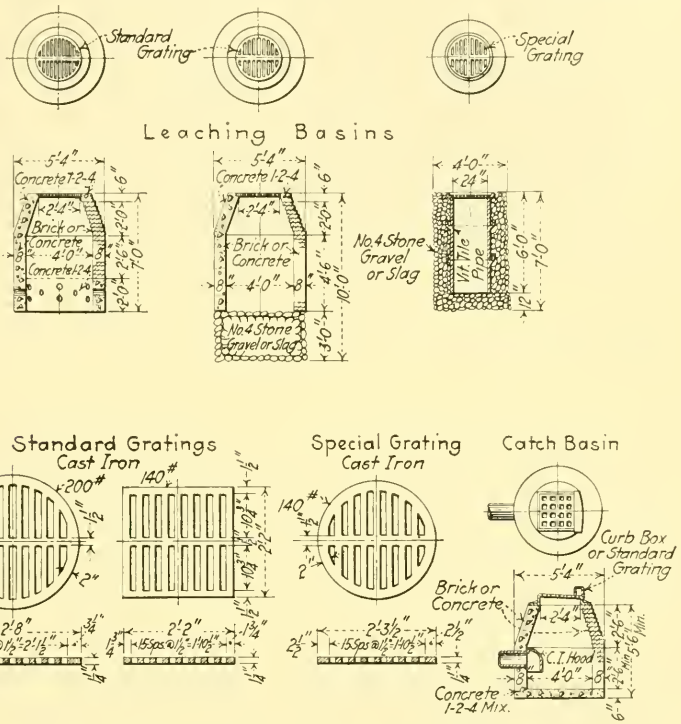


FIG. 195.—Typical rural highway catch basins.

gate and generally a gap is left in the fence across which a shallow pit 2 to 3 ft. deep is dug and this is covered with a slat grating which cattle will not walk but which can be driven over by automobiles.

Fences.—Ordinary right-of-way and snow fences are shown in Figs. 202 and 203.

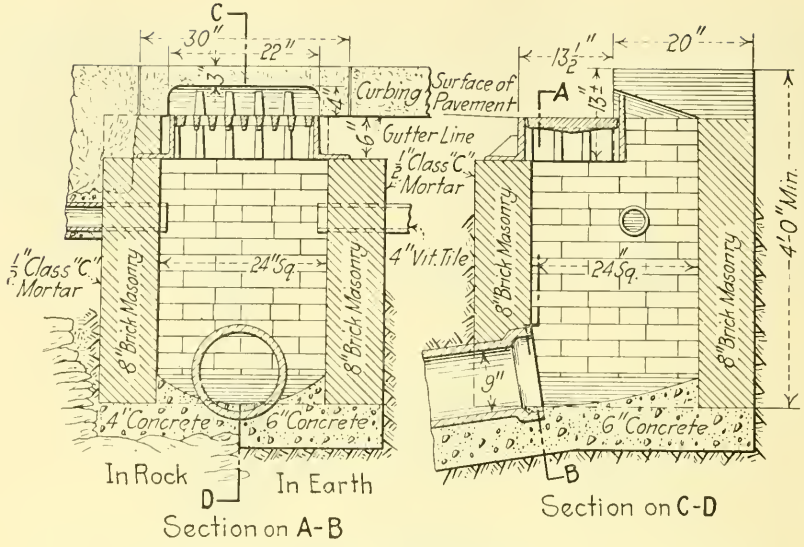


FIG. 196.—Typical curb inlet catch basin (City of Rochester Standard).

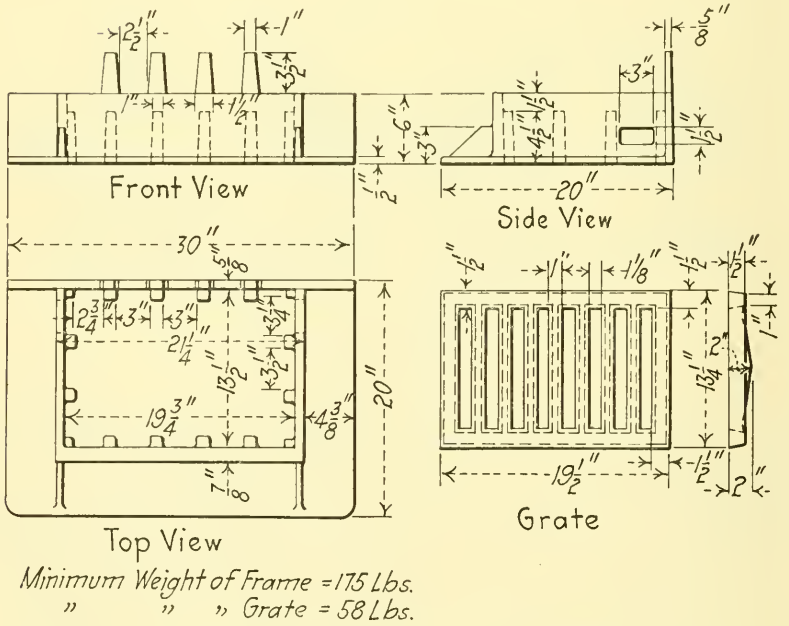
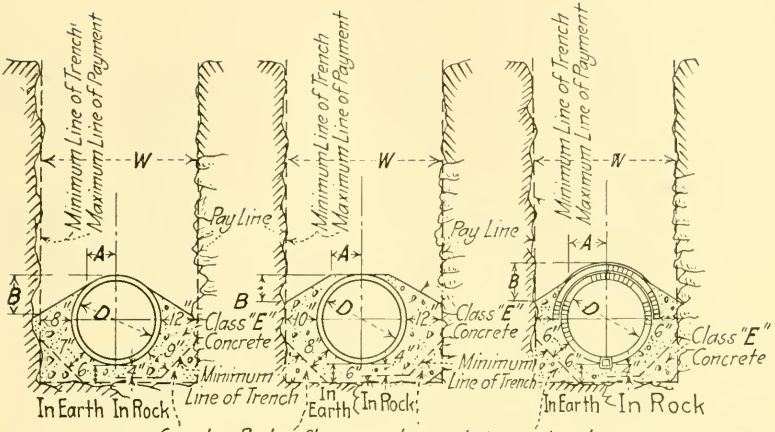


FIG. 196A.—Typical curb inlet catch basin (City of Rochester Standard).


Minimum Line of Trench
Maximum Line of Payment
W
Pay Line
A
B
D
Class "E" Concrete
Minimum Line of Trench
In Earth
In Rock
Gravel or Broken Stone may be used when ordered
Section of Trench for Vitrified Tile Pipe 18" and under in diameter
Section of Trench for Vitrified Tile Pipe over 18" in diameter
Section of Trench for Brick Sewers

Classification for Concrete					
Class	A	B	C	D	E
Prop.	1:1½:3	1:2:4	1:2½:5	1:3:6	1:8
Aggregate	¼" to 1" Stone	¼" to 1" Stone	¼" to 1½" Stone	¼" to 2" Stone	Torpedo Gravel

Classification for Mortar				
Class	A	B	C	D
Prop.	1:1	1:1½	1:2½	1:3

Pipe Sewers 18" and Under							
In Earth				In Rock			
D	W	A	B	D	W	A	B
6"	23¼"	2⅝"	6¼"	6"	31¼"	2⅝"	8⅝"
8"	25½"	3⅜"	6¾"	8"	33½"	3⅜"	9⅛"
9"	26¾"	3¾"	7⅛"	9"	34¾"	3¾"	9⅜"
10"	27¾"	4⅛"	7⅜"	10"	35¾"	4⅛"	9⅝"
12"	30"	5"	7⅞"	12"	38"	5"	10⅛"
15"	33½"	6¼"	8¾"	15"	41½"	6¼"	11"
18"	37"	7⅜"	9⅜"	18"	45"	7⅜"	11⅞"

Pipe Sewers Over 18"							
In Earth				In Rock			
D	W	A	B	D	W	A	B
20"	43½"	7½"	8¼"	20"	47½"	7½"	9⅜"
22"	45⅞"	8¼"	8½"	22"	49⅝"	8¼"	9⅝"
24"	48"	9"	8⅝"	24"	52"	9"	9⅞"
27"	51⅝"	10¼"	9⅞"	27"	55½"	10¼"	10¼"
30"	55⅞"	11¼"	9⅜"	30"	59"	11¼"	10⅝"

Brick Sewer 30" and Over in Rock and Earth			
D	W	A	B
30"	4'-11"	16½"	14⅜"
33"	5'-2"	17⅝"	15"
36"	5'-5"	18¾"	15⅝"
42"	5'-11"	20⅞"	17"
45"	6'-2"	21⅞"	17¾"
48"	6'-5"	23"	18⅝"

FIG. 196*B*.—Miscellaneous Street Standards (City of Rochester). Sewer Trenches.

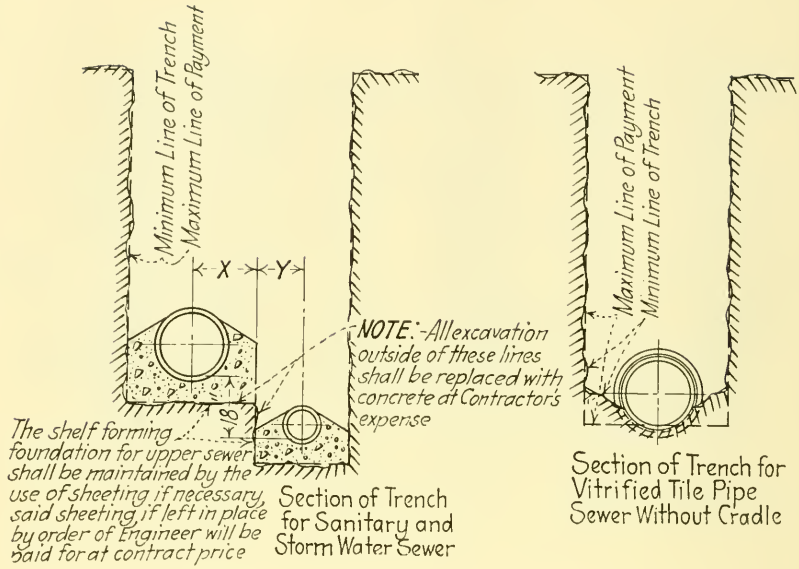

Minimum Line of Trench
Maximum Line of Payment
X
Y
NOTE:-All excavation outside of these lines shall be replaced with concrete at Contractor's expense
The shelf forming foundation for upper sewer shall be maintained by the use of sheeting if necessary, said sheeting, if left in place by order of Engineer will be paid for at contract price
Section of Trench for Sanitary and Storm Water Sewer
Maximum Line of Payment
Minimum Line of Trench
Section of Trench for Vitrified Tile Pipe Sewer Without Cradle

Table Showing Distances X and Y for Sewers laid in the same Trench, the Distance between center lines of Pipes = X + Y. The total width of Trench paid for and the minimum excavation width = 2X + 2Y

Kind	Size	In Earth		In Rock		Kind	Size	In Earth		In Rock	
Tile Pipe		X	Y	X	Y	Tile Pipe		X	Y	X	Y
" "	6"	11 5/8"	11 5/8"	15 3/4"	15 3/4"	" "	24"	24"	24"	26"	26"
" "	8"	12 3/4"	12 3/4"	16 7/8"	16 7/8"	" "	27"	25 3/4"	25 3/4"	27 3/4"	27 3/4"
" "	9"	13 3/8"	13 3/8"	17 3/8"	17 3/8"	" "	30"	28"	28"	29 1/2"	29 1/2"
" "	10"	13 7/8"	13 7/8"	17 5/8"	17 5/8"	Brick	30"	2'-5 1/2"	2'-5 1/2"	2'-5 1/2"	2'-5 1/2"
" "	12"	15"	15"	19"	19"	"	33"	2'-7"	2'-7"	2'-7"	2'-7"
" "	15"	16 3/4"	16 3/4"	20 3/4"	20 3/4"	"	36"	2'-8 3/8"	2'-8 3/8"	2'-8 3/8"	2'-8 3/8"
" "	18"	18 1/2"	18 1/2"	22 1/2"	22 1/2"	"	42"	2'-11 1/2"	2'-11 1/2"	2'-11 1/2"	2'-11 1/2"
" "	20"	21 3/4"	21 3/4"	23 3/4"	23 3/4"	"	45"	3'-1"	3'-1"	3'-1"	3'-1"
" "	22"	23"	23"	24 3/4"	24 3/4"	"	48"	3'-2 1/2"	3'-2 1/2"	3'-2 1/2"	3'-2 1/2"

FIG. 196C.—Miscellaneous Street Standards (City of Rochester). Sewer Trenches.

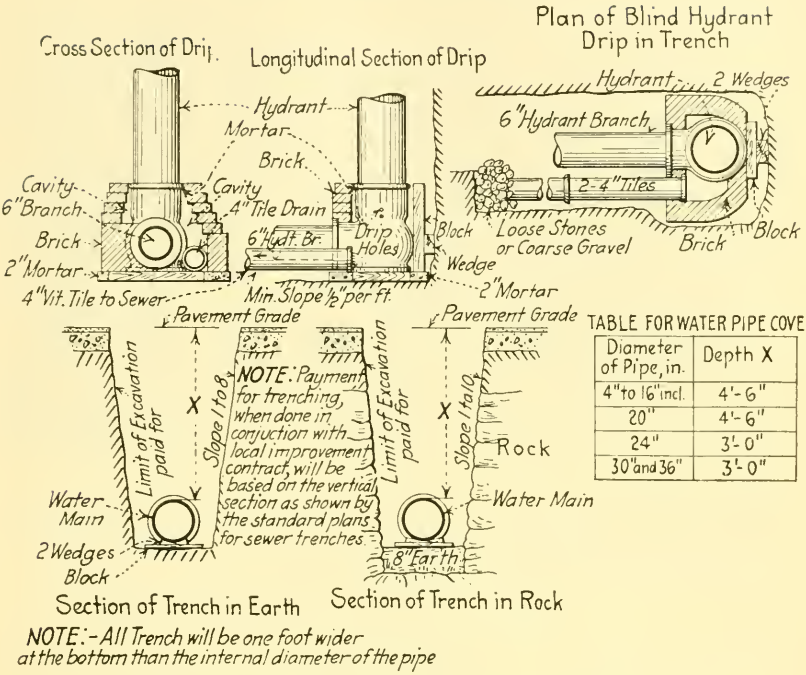
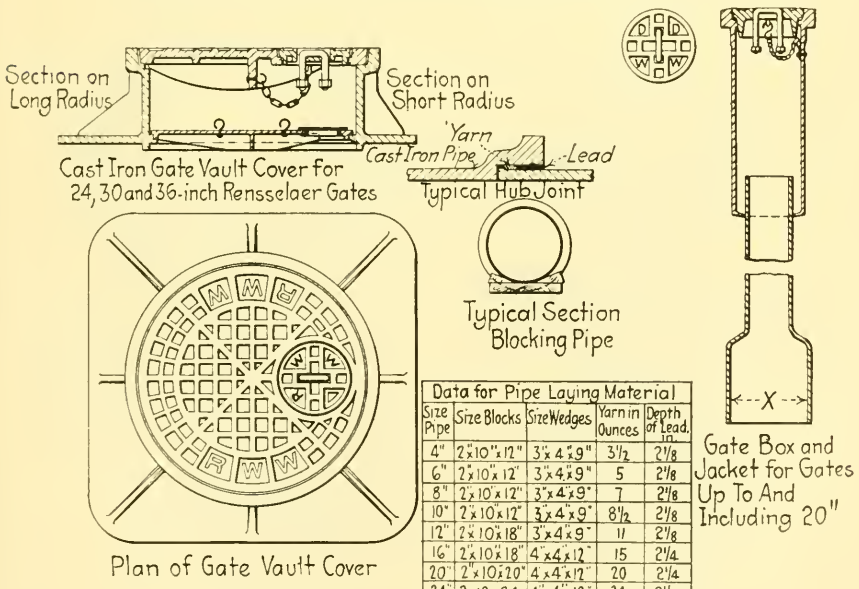


TABLE FOR WATER PIPE COVER

Diameter of Pipe, in.	Depth X
4" to 16" incl.	4'-6"
20"	4'-6"
24"	3'-0"
30" and 36"	3'-0"

FIG. 196*D*.—Miscellaneous Street Standards (City of Rochester).


Section on Long Radius
Section on Short Radius
Cast Iron Gate Vault Cover for 24, 30 and 36-inch Rensselaer Gates
Yarn
Cast Iron Pipe
Lead
Typical Hub Joint
Typical Section Blocking Pipe
Plan of Gate Vault Cover
X
Gate Box and Jacket for Gates Up To And Including 20"

Data for Pipe Laying Material

Size Pipe	Size Blocks	Size Wedges	Yarn in Ounces	Depth of Lead, in.
4"	2"x10"x12"	3"x4"x9"	3½	2⅛
6"	2"x10"x12"	3"x4"x9"	5	2⅛
8"	2"x10"x12"	3"x4"x9"	7	2⅛
10"	2"x10"x12"	3"x4"x9"	8½	2⅛
12"	2"x10"x18"	3"x4"x9"	11	2⅛
16"	2"x10"x18"	4"x4"x12"	15	2¼
20"	2"x10"x20"	4"x4"x12"	20	2¼
24"	2"x12"x24	4"x4"x12"	24	2½
30"	3"x12"x30"	4"x6"x12"	33	2¾
36"	4"x12"x36"	4"x6"x12"	48	3

FIG. 196*E*.—Miscellaneous Street Standards (City of Rochester). Water Trenches, etc

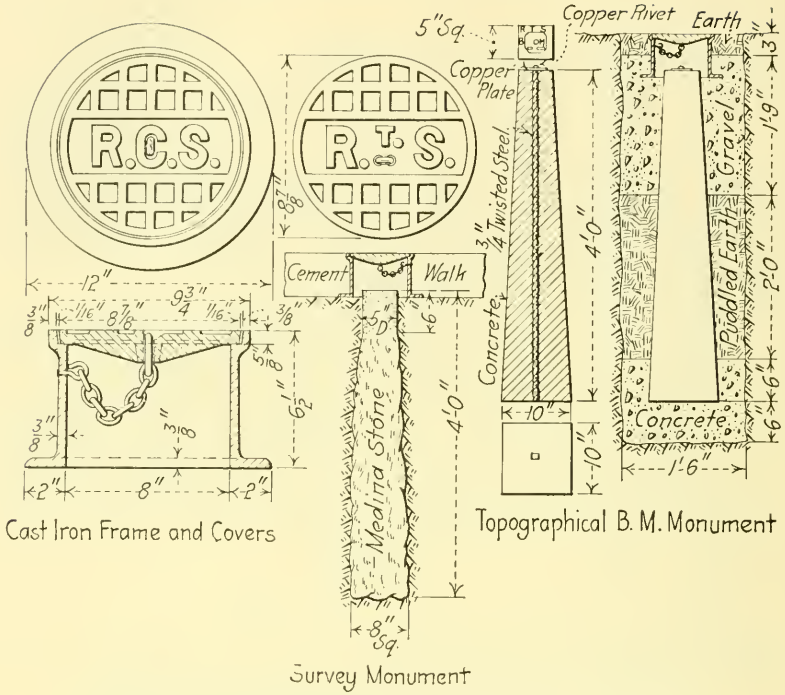


FIG. 196*F*.—Miscellaneous Street Standards (City of Rochester).

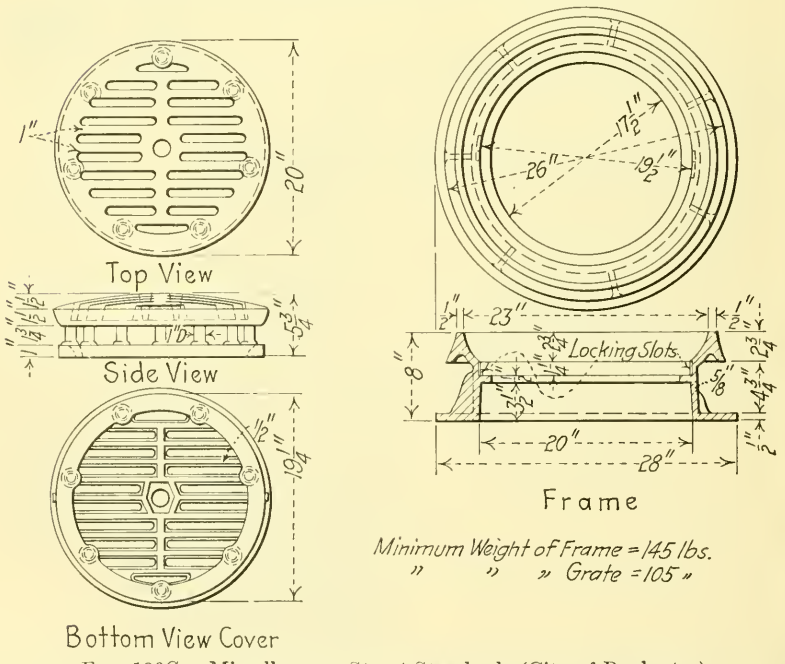


FIG. 196*G*.—Miscellaneous Street Standards (City of Rochester).

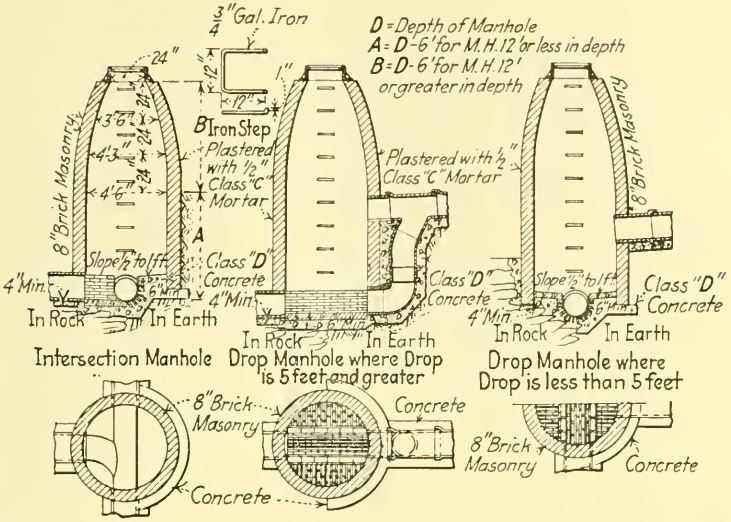

3/4" Gal. Iron
D = Depth of Manhole
A = D - 6' for M.H. 12' or less in depth
B = D - 6' for M.H. 12' or greater in depth
24"
12"
1"
17"
B Iron Step
Plastered with 1/2" Class "C" Mortar
8" Brick Masonry
3'6"
4'3"
4'6"
24"
A
Slope 1/2" to 1 ft.
Class "D" Concrete
4" Min.
6" Min.
In Rock
In Earth
Intersection Manhole
Drop Manhole where Drop is 5 feet and greater
Plastered with 1/2" Class "C" Mortar
Drop Manhole where Drop is less than 5 feet
8" Brick Masonry
Concrete
NOTES-
Benchwalls - in manholes for sewers 15" in diam. and smaller to be built to top of pipe - for sewers 15" to 30" in diam. 15" high - for larger sewers to be built to spring line. No benchwalls required in dead end manholes but bottoms to be properly dished. Benchwalls in drop manholes to be paved with vitrified brick. Inverts in Manholes may be built of either tile or brick. Walls to be backed with concrete if directed by engineer. Sanitary Manholes to be plastered on outside.

Fig. 197.—Miscellaneous Street Standards (City of Rochester). Manholes.

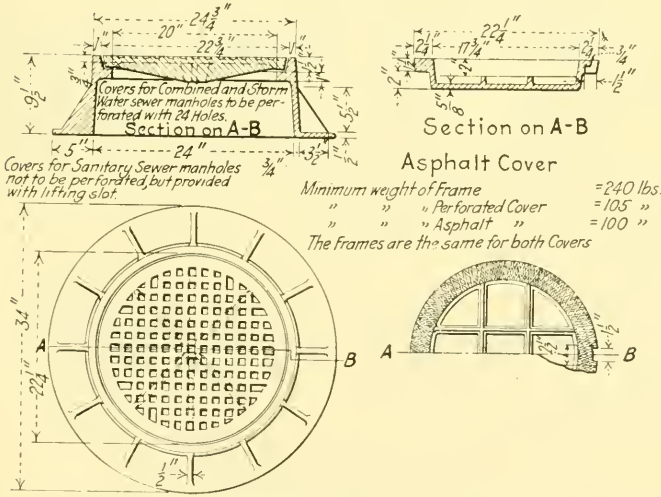


Fig. 197A.—Miscellaneous Street Standards (City of Rochester). Manhole Covers.

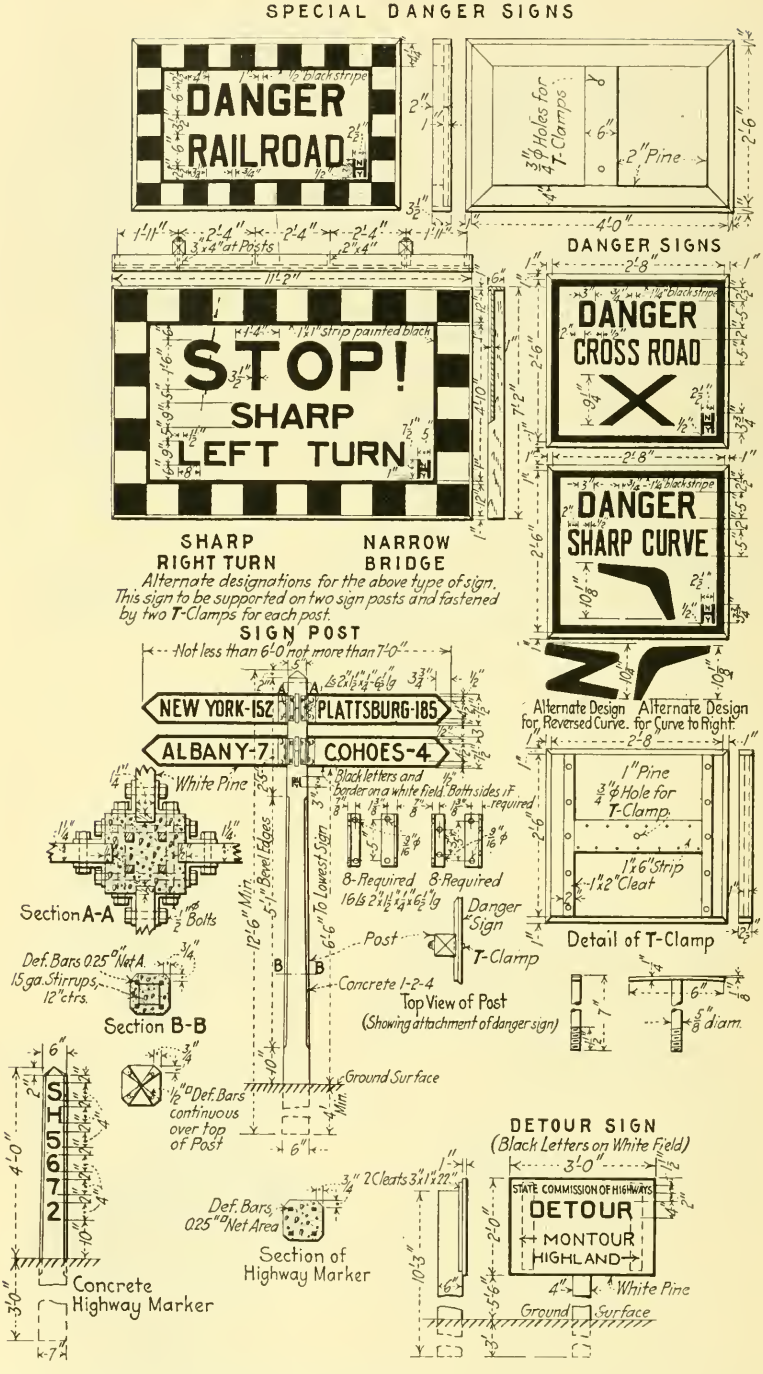


FIG. 198.—Guide and danger signs (New York State, 1923).

FIG. 199.—Excellent type of danger sign. This sign however did not prevent accident. Note the broken guard rail where car left road and overturned in creek seriously injuring the driver. Radius of curvature at this point 50 ft. This illustrates the fact that signs do not make dangerous alignment safe. The checkerboard type of border is very effective.

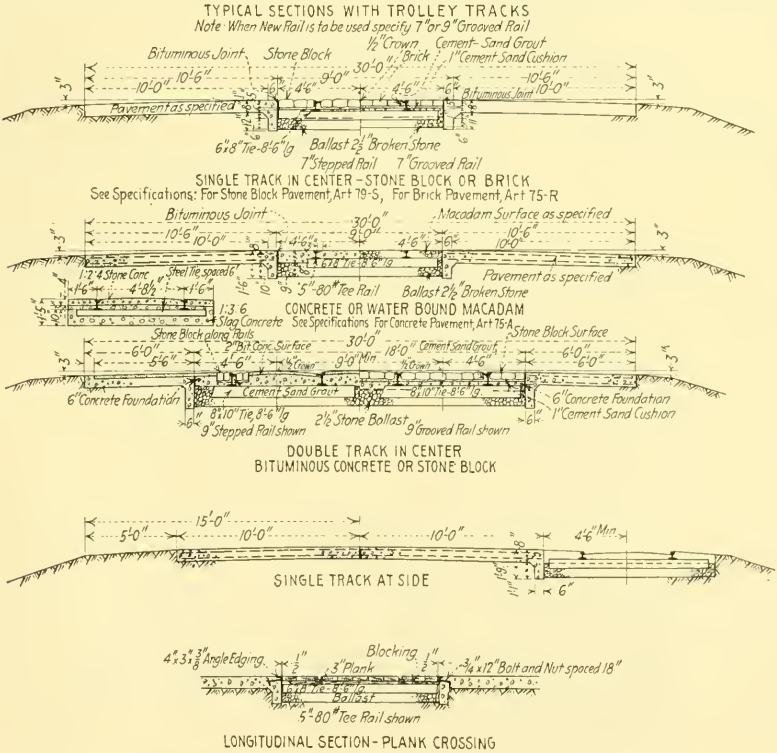

TYPICAL SECTIONS WITH TROLLEY TRACKS
Note: When New Rail is to be used specify 7"or 9"Grooved Rail
SINGLE TRACK IN CENTER - STONE BLOCK OR BRICK
See Specifications: For Stone Block Pavement, Art 79-S, For Brick Pavement, Art 75-R
CONCRETE OR WATER BOUND MACADAM
See Specifications For Concrete Pavement, Art 75-A
DOUBLE TRACK IN CENTER
BITUMINOUS CONCRETE OR STONE BLOCK
SINGLE TRACK AT SIDE
LONGITUDINAL SECTION - PLANK CROSSING

FIG. 200.—Typical car track sections (State of New Jersey, 1922).

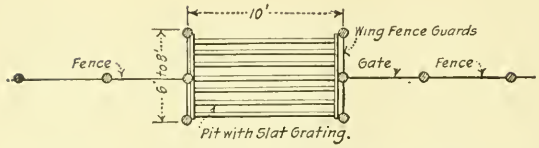


FIG. 201.—Cattle guard in New Mexico.

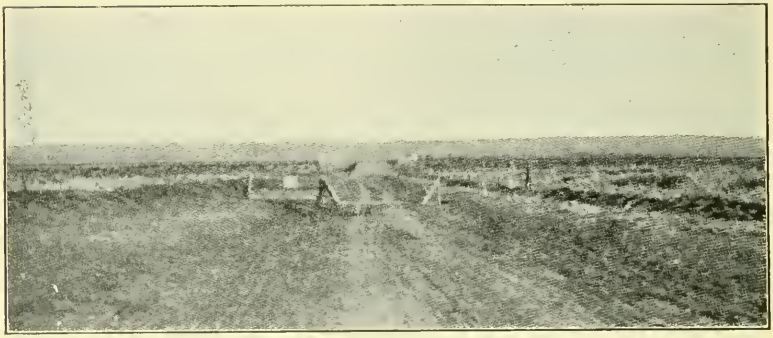


FIG. 201*A*.—Cattle guard.

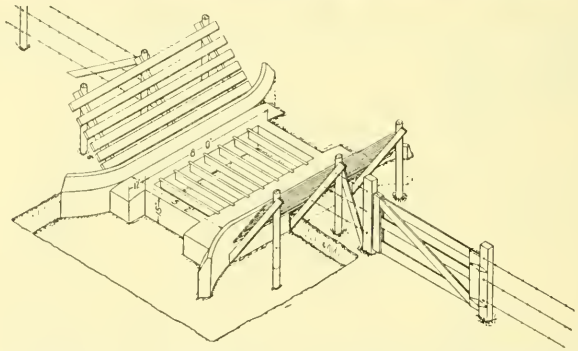


FIG. 201*B*.—Type of crossing used extensively in Western Kansas.

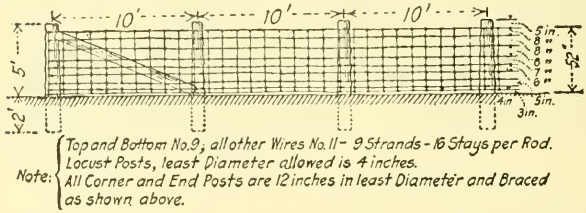


FIG. 202.—A good standard right-of-way fence.

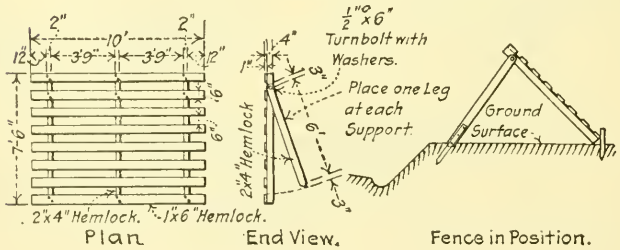


FIG. 203.—Snow fence detail.

CONCLUSION OF VOLUME

This book completes the discussion of general principles of highway design, construction and maintenance. The effective application of these general principles depends on the actual methods used in every day work for specific roads.

The next volume will take up a discussion of detail methods of survey, design, estimating and construction. The essential general attitude in regard to detail methods which must be continually borne in mind and impressed on the engineering force can be briefly summarized as follows:

The survey work must be *accurate and complete* as it provides the fundamental information for the design and the accurate estimate and measurement of quantities. Satisfactory survey work will range in cost from $100 to $400 per mile and any effort to cut cost below that required for excellent work is very short sighted policy. Careless work is often done in order to cut the apparent cost of engineering but it generally adds to the final total cost and is unsatisfactory to both engineers and contractors.

Effective design is based on the principle of the preparation of *alternate comparative designs* in order to pick the most suitable or economical solution. By the use of this method of alternate designs a good engineer will reduce construction costs at least 10 to 20 per cent below that obtained by the usual stereotyped application of standards with little thought to the local problem. First class office design costs from $150 to $400 per mile and any effort to cut this cost below the amount required for thorough design is poor economy as we know from experience over twenty years time.

Estimates of quantities should be liberal in order to avoid the necessity of supplementary agreements during the progress of construction but in order not to mislead the contractor in making his bid it is necessary for the estimates to show the probable minimum amount for each item with a statement of the amount allowed for contingencies. *Cost estimates should be fairly liberal.* They should never be below an amount which will insure a reasonable profit with ordinarily favorable luck. This matter of cost is very important as a poor contract price is almost certain to result in inferior work even with good inspection control.

The essential of construction inspection is insistence on *good quality of work without needless interference with the contractors choice of methods.* Construction practice is the most essential part of successful highway programs and is generally the poorest managed part of the engineering program. This is largely due to the policy of low pay for field engineers and inspectors. Under this general policy it is impossible to get high grade men who will give it their entire undivided attention. low grade

men are no match for high grade contractors or even well paid foremen and the results are often not very creditable to the inspection force. Effective supervision of construction costs from $600 to $1,000 per mile and any effort to cut cost on the score of engineering pay roll economy is political bunkum and very poor economic policy.

Lack of thoroughness and care is a common trait which shows in extreme form in public works programs. It is most certainly desirable to combat this tendency which is very well illustrated by the anecdote of the American tourist in Spain who on hearing that it had taken 500 years to build a famous cathedral remarked, "Well in God's country where I come from we could build one of those things and have it fall down on us, all inside of five years."

APPENDICES

MATERIALS AND TESTS

APPENDIX A

Introductory Note.—Appendix A is essentially a reprint of the chapter on materials from Harger and Bonney's "Highway Handbook" with some additions describing recent modifications in testing methods. This appendix duplicates a small amount of the data from different chapters but has not been rearranged as such duplications add to the ease of reference.

Materials.—The selection of materials is an important part of the design. Most municipal and State Departments have well equipped laboratories for testing stone, gravels, brick, bitumens, cements, etc. The object of these tests is to determine the physical and chemical properties that have a particular bearing on the action of the materials under construction conditions. While these conditions are not attained they are approximated and by a comparison of the laboratory results with the actual performance of the different materials in practice a relation can be established that is useful as a basis for judgment.

We are greatly indebted to H. S. Mattimore and J. E. Myers who have rearranged and brought up to date much of the material on tests and their significance.

This appendix gives a brief statement of the desirable qualities and the tests for:

1. Top course, macadam stone.
2. Screenings.
3. Bottom course, macadam stone.
4. Bottom course and subbase fillers.
5. Brick.
6. Bituminous binders.
7. Cement.
8. Fine aggregate for cement or asphaltic concretes.
9. Coarse aggregate for cement concrete.
10. Sand clay and gravel tests.

The following instructions for sampling materials are quoted from the New York Manual:

Sampling.—Amounts of material required for laboratory tests are as follows:

Samples of material will be taken by a duly authorized employee of the Department, in its place of occurrence or manufacture or delivery by carrier. These samples must be taken from different parts of the lot of material to be tested, so as to be fairly representative, and must be unmixed with foreign substances and placed in clean and safe receptacles; and they must conform in all respects to the requirements given under the special headings. They must be carefully and securely packed, enclosing notification slip properly protected from wear and injury, and sent by express "collect" to the "Bureau of Tests, State Highway Commission, Albany, N. Y." a postal card notice being mailed at the same time. Envelopes, scoops, cans, thermometers, etc. for use in taking the samples, may be had from the Bureau of Finance and Audit at Albany.

In the case of materials sampled at place of manufacture, check samples may be required; these are to be taken and treated the same as ordinary samples, except that the packages must be marked "Check Samples," and the use of the material needed not be prohibited pending the results of the check tests.

Sand and Gravel.—The character of the supply, whether from stream bed, bank, crusher bins, etc., is to be stated; also the use for which it is intended, whether for concrete foundations or other structures, binder for waterbound macadam, filler or wearing carpet or blotter for bituminous macadam, or for aggregate in waterbound or bituminous macadam, etc.

Material which will all pass through a $\frac{1}{4}$-in. screen will be considered sand. Each sample of sand or screenings shall be $\frac{3}{4}$ cu. ft. in volume; of gravel $1\frac{1}{2}$ cu. ft.

A small sample shall be taken from each test sample sent, and be kept on the contract as a measure of the quality of material.

Each sample is to be shipped in a tight box or in a clean, closely woven bag from which there will be no leakage; the usual identification slip is to be enclosed. In numbering samples, sand and gravel are to be treated as one material, not as two.

Notification of acceptance or rejection may be expected to arrive at the Division office 20 days after the submission of the samples and data, providing the need of a retest does not cause delay.

Cement.—One sample is to be taken from at least every 10 bbl. or every 40 bags, care being taken to properly distribute the sampling over the lot. Each sample shall be not less than 27 cu. in. in volume or enough to fill a 3-in. cube. Whenever possible, samples should be forwarded in envelopes furnished by the Commission for that purpose, the envelopes being filled to the line marked thereon.

The individual samples are not to be numbered, but each group or lot of these samples representing a single boat load or car load is to be given a lot number, and these lot numbers are to run consecutively. Not more than one boat load or car load is to be represented by 1 lot number.

Receipt of notification of acceptance or rejection of cement sampled at destination may be expected to arrive at the Division Engineer's office 12 days after the submission of the samples and data. If cement is held for 28-day tests the Division Engineer will be notified accordingly.

Concrete.—The concrete on each highway must be sampled for testing, the samples being taken at random from the batches used and being molded at the place and time of mixing. The work need not be delayed pending the results of the tests.

Each sample shall be a pair of cubes measuring 6 in. on the edge or of cylinders 8 in. in diameter and 16 in. long; the sample is to be made in such manner as to fairly represent the concrete going into the structure. At least one sample is to be taken, and as many more as seem to be required by changes in the character of any ingredient or by any other consideration.

In concrete pavement work (whether foundation or top course) 1 pair of cubes or cylinders should be sent for every 500 cu. yd. Not less than two pairs are to be sent, however small the pavement.

The sample must remain in the mold two days, then be buried in clean sand to age under the same conditions as the material in the structure. On the twenty-first day the samples shall be taken out and shipped.

Each sample is to have its number painted on each piece, and is to be shipped in a box, properly protected from breakage and surface chipping, accompanied by the usual included

identification slip and the postal notification. Especially must the class of concrete, the purpose for which it is used (kind of structure and portion), and the date and time of day when sample was mixed, be stated.

Bituminous Material.— When material is shipped in barrels one sample is to be taken for every 20 or 25 bbl., the sampling being properly distributed over the lot.

When material is shipped in tank cars one sample is to be taken from every 2,000 or 2,500 gal. the samples being taken from equally distributed levels in the car:

When mineral bitumen is shipped in loose bulk, one sample is to be taken for every 5 or 6 tons, the samples being taken from different levels and different locations in the lot and never from the surface of the material.

Each sample shall be not less than 14 cu. in. in volume, which volume is slightly less than ½ pt. or about the size of a 1-lb. paint can.

It should be remembered that the bituminous material will flow at summer temperature or thereabouts, and consequently great care should be used in sealing cans and doing up packages. Whenever possible, samples should be forwarded in the cans furnished by the Commission for the purpose.

The individual samples are not to be numbered, but each group or lot representing a single boat load or car load is to be given a lot number, and these lot numbers are to run consecutively; not more than one boat load or car load of material is to be represented by one lot number.

In order to check the weighing and marking of bituminous material shipped in barrels, one unopened barrel out of every car load of approximately 65 bbl., or a proportionate number of barrels for each boat load, is to be selected at random and weighed. The gross weight found, and the gross weight marked on the barrel, are to be entered on the Monthly Bituminous Material Reports or the information may be recorded elsewhere and submitted to the Bureau of Tests. Any noticeable difference between the gallonage marked on a barrel and the gallonage found therein, must be reported to the Headquarters office at Albany.

The unit of measure for bituminous material is the gallon measured at the temperature of 60°F. If the volume of material is measured when hot, allowance should be made for expansion according to the following table, which will apply approximately to all of the different classes of bituminous material at present used on the State highways:

Increase in volume of various classes of bituminous material when heated from 60°F.

To 400°F. is approximately 12 per cent.
To 350°F. is approximately 10 per cent.
To 300°F. is approximately 8 per cent.
To 250°F. is approximately 6 per cent.
To 200°F. is approximately 4 per cent.
To 150°F. is approximately 2 per cent.

Stone.—Rotten or partially disintegrated stone, or weathered specimens from the surface of a quarry or ledge, are not to be submitted.

Samples of quarry or ledge stone must be representative of the sound, fresh, interior stone of the ledge or quarry. Such samples may be secured either by blasting or by breaking up with the sledge. If all material is of the same variety, texture, etc., one sample will suffice. If, however, there are different varieties separate samples are to be taken of each and report made as to the extent, giving details as to location and position for use.

All field stone, whether in walls, piles, or scattered over the ground, which might be used, must be examined and a representative sample taken. When two or more varieties of great difference in quality or texture are observed to exist, separate samples are to be taken of each, and report made as to the percentage of each kind, the amount of small stone which might run through the crusher without action, and the percentage of disintegrated or badly weathered rock present.

In taking samples from the output of crushers, 15 lb. of crushed material not smaller then 1½ in. in size shall be taken, and also one piece at least 3 × 4 × 5 in. shall be procured from the source of supply.

Each sample shall weigh not less than 25 lb. nor more than 35 lb. If the entire sample submitted is a single piece of stone, it should be remembered that a piece about the size of a man's head will weigh 25 or 30 lb. While not less than 25 lb. are absolutely necessary

in each sample, care should be taken to see that the samples do not weigh over 35 lb. One piece of each sample shall be at least 3 by 4 by 5 in.

Each sample is to be given a number running consecutively in each Division. This number must contain both the Division number and the sample number; thus, Sample 42 from Division 1 would be marked "1–42." Paint or Higgins' drawing ink may be used to mark directly on the sample, or a label or tag may be securely fastened thereto.

Samples may be shipped in boxes, burlap, grain bags, cement bags, etc. It is preferred that stone be shipped in a strong bag or in a double bag which may be formed by placing 1 bag inside of another. If shipping in a single bag which the sample only partially fills, the bag should be securely tied just above the sample and the remaining unfilled part of the bag folded back so as to completely envelop the stone and the portion of the bag containing it; this folded back part should then be securely tied on the other side of the sample; this makes a tying of the bag on two sides of the stone, and permits two thicknesses of the bag to completely surround the stone, and if securely tied is as satisfactory as a double bag.

Receipt of notification of acceptance or rejection of stone may be expected to arrive at the Division Engineer's office 12 days after the submission of the samples and data, provided acceptance or rejection is not deferred awaiting a retest.

The location of source of supply is to be expessed by an index number according to the system used in the Government Office at Washington, which is, that each quadrangle of the U. S. Geological Survey Sheet is divided into nine sections numbered from 1 to 9 inclusive, as shown in the following plan:

1	2	3
4	5	6
7	8	9

The north and south sides of each section are then divided into 22 spaces designated from A to V and the east and west sides into 32 spaces designated 1 to 32, so that the location of the stone may be closely defined, as for example, Quadrangle Albany, Section 7, Letter J, Number 13, which when abbreviated would read "Albany-7-J-13."

Paving Brick.—A sufficient number of samples in every case is to be taken to insure the use of brick of proper quality, but it should also be borne in mind that the charges for transportation and testing of brick are high, and only the smallest number of samples necessary for the purpose should be submitted. At least 1 sample is to be taken from every 200,000 brick or less. Each sample shall consist of 30 bricks.

If in a shipment or several shipments of the same make and kind of brick there appear to be different classes of brick—such as brick of different degrees of burning, for example—a full sample of each class is to be taken.

Each brick selected for the sample is to be free from cracks or other defects which would prevent its passing inspection at the road, for the sample must represent bricks which will not be culled out. Especially is it forbidden that any person financially interested in the manufacture or use of brick be present when samples are taken.

Each sample (consisting of 30 bricks) shall receive a number, the numbers to run consecutively for each road.

The sample shall be shipped in wooden boxes, not more than 10 or 12 bricks being put in 1 box on account of weight and strength of package.

Notification of acceptance or rejection of brick sampled at destination may be expected to arrive at the Division Engineer's office 9 days after submission of samples and data, providing the need of a retest does not cause delay.

Asphalt Block.—A sufficient number of samples in every case is to be taken to insure the use of block of proper quality, but it should also be borne in mind that transportation and testing costs are high, and only the smallest number of samples necessary should be submitted. At least 1 sample is to be taken from every 100,000 blocks or less. Each sample shall consist of two blocks.

If in a shipment or several shipments of the same make and kind of block there appear to be different classes of block, a full sample of each class is to be taken.

Each block selected for the sample is to be free from every defect that would prevent its passing inspection at the road, for the sample must represent blocks which will not be culled out.

Each sample (consisting of two blocks) shall receive a number, the numbers to run consecutively for each road.

The sample shall be shipped in a wooden box, with usual identification card and postal notice.

Notification of acceptance or rejection of block sampled at destination may be expected to reach the Division Engineer's office 14 days after submission of samples and data, providing the need of a retest does not cause delay.

Acceptance.—Upon completion of the testing of any set of samples the Division Engineer is notified of the acceptance or rejection of the material, and transmits the statement to the engineer in charge of the contract.

STONE FOR THE SURFACING OF MACADAM ROADS

Stone for use in the surfacing of a macadam road should be hard and tough to withstand the abrasive action of team traffic and the vibratory action of high-speed motor vehicles and should not contain any minerals that are likely to disintegrate rapidly under influence of weather conditions.

To determine the relative hardness, toughness and power to resist abrasive and impact action of traffic, stones are subjected to the following tests:

1. Abrasion.
2. Hardness.
3. Toughness.
4. Specific gravity.
5. Absorption.
6. Fracture.
7. Geological classification.

Abrasion Test.[1]—The machine shall consist of 1 or more hollow iron cylinders; closed at one end and furnished with a tightly fitting iron cover at the other; the cylinders to be 20 cm. in diameter and 54 cm. in depth, inside. These cylinders are to be mounted on a shaft at an angle of 30 deg. with the axis of rotation of the shaft.

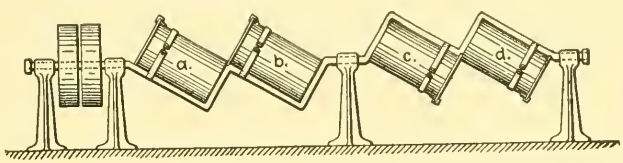


FIG. 204.—Deval rattler.

At least 30 lb. of coarsely broken stone shall be available for a test. The rock to be tested shall be broken in pieces as nearly uniform in size as possible, and as nearly 50 pieces as possible shall constitute a test sample. The total weight of rock in a test shall be within 10 g. of 5 kg.

All test pieces shall be washed and thoroughly dried before weighing. Ten thousand revolutions, at the rate of between 30 and 33 per minute, shall constitute a test. Only the percentage of materials worn off which will pass through a 0.16-cm. ($\frac{1}{16}$-in.) mesh sieve shall be considered in determining the amount of wear. This may be expressed either as the percentage of the 5 kg. used in the test, or the French coefficient, which is in more general use, may be given; that is, coefficient of wear $= 20 \times \frac{20}{w} = \frac{400}{w}$, where w is the weight in grams of the detritus under 0.16 cm. ($\frac{1}{16}$ in.) in size per kilogram of rock used.

[1] American Society of Testing Materials.

Conversion Table Per Cent of Wear to French Coefficient

French coefficient	Per cent of wear	French coefficient	Per cent of wear
20.0	2	8.0	5
13.3	3	6.7	6
10.0	4	5.7	7

Hardness.—Hardness is determined by a Dorry machine. A stone cylinder 25 cm. in diameter, obtained by a diamond core drill from the material to be tested, is weighed and placed in the machine so that one end rests on a horizontal cast-iron grinding disk with a pressure of 25 g. per square centimeter. The disk is revolved 1,000 times during which standard crushed quartz sand about 1½ mm. in diameter is automatically fed to it. The cylinder is then removed and weighed and the coefficient of hardness obtained by the formula $20-\frac{1}{3}$ the loss in weight, expressed in grams. In order to get reliable results two cylinders are generally used, each one being reversed end for end during the test.

Test for Toughness.[1]—(1) Test pieces may be either cylinders or cubes, 25 mm. in diameter and 25 mm. in height, cut perpendicular to the cleavage of the rock, Cylinders are recommended as they are cheaper and more easily made.

2. The testing machine shall consist of an anvil of 5 kg. weight, placed on a concrete foundation. The hammer shall be of 2 kg. weight, and dropped upon an intervening plunger of 1 kg. weight, which rests on the test piece. The lower or bear-surface of this plunger shall be of spherical shape having a radius of 1 cm. This plunger shall be made of hardened steel, and pressed firmly upon the test piece by suitable springs. The test piece shall be adjusted, so that the center of its upper surface is tangent to the spherical end of the plunger.

3. The test shall consist of a 1 cm. fall of the hammer for the first blow, and an increased fall of 1 cm. for each succeeding blow until failure of the test piece occurs. The number of blows necessary to destroy the test piece is used to represent the toughness, or the centimeter-grams of energy applied may be used.

Determination of the Apparent Specific Gravity of Rock.[1]—The apparent specific gravity of rock shall be determined by the following method: First, a sample weighing between 29 and 31 g. and approximately cubical in shape shall be dried in a closed oven for 1 hour at a temperature of 110°C. (230°F.) and then cooled in a desiccator for 1 hour; second, the sample shall be rapidly weighed in air; third, trial weighings in air and in water of another sample of approximately the same size shall be made in order to determine the approximate loss in weight on immersion; fourth, after the balances shall have been set at the calculated weight, the first sample shall be weighed as quickly as practicable in distilled water having a temperature of 25°C. (77°F.); fifth, the apparent specific gravity of the sample shall be calculated by the following formula:

$$\text{Apparent specific gravity} = \frac{W}{W - W_1}$$ in which W = the weight in grams of the sample in air and W_1 = the weight in grams of the sample in water just after immersion.

Finally, the apparent specific gravity of the rock shall be the average of three determinations, made on three different samples according to the method above described.

Determination of the Absorption of Water per Cubic Foot of Rock.[1]—The absorption of water per cubic foot of rock shall be determined by the following method: First, a sample weighing between 29 and 31 g. and approximately cubical in shape shall be dried in a closed oven for 1 hour at a temperature of 110°C. (230°F.) and then cooled in a desiccator for 1 hour; second, the sample shall be rapidly weighed in air; third, trial weighings in air and in water of another sample of approximately the same size shall be made in order to determine the approximate loss in weight on immersion; fourth, after the balances shall have been set at the calculated weight, the first sample shall be weighed as quickly as pos-

[1] American Society of Testing Materials.

sible in distilled water having a temperature of 25°C. (77°F.); fifth, allow the sample to remain 48 hours in distilled water maintained as nearly as practicable at 25°C. (77°F.) at the termination of which time bring the water to exactly this temperature and weigh the sample while immersed in it; sixth, the number of pounds of water absorbed per cubic foot of the sample shall be calculated by the following formula:

Pounds of water absorbed per cubic foot $= \frac{W_2 - W_1}{W - W_1} \times 62.24$ in which W = the weight in grams of sample in air, W_1 = the weight in grams of sample in water just after immersion, W_2 = the weight in grams of sample in water after 48 hours immersion, and 62.24 = the weight in pounds of a cubic foot of distilled water having a temperature of 25°C. (77°F.).

Finally, the absorption of water per cubic foot of the rock, in pounds, shall be the average of three determinations made on three different samples according to the method above described.

Fracture.—Stone suitable for road work should crush in cubical shapes rather than in thin, flat pieces and preferably with rough, jagged fracture that it may interlock firmly under action of the roller.

Geological Classification.—The geological classification is determined from an examination with a microscope or powerful hand glass, and a consideration of its origin. Great refinements are avoided as the general classification is all that is necessary to the highway engineer after the physical qualities are ascertained by test.

TABLE 44.—GEOLOGICAL CLASSIFICATION

Class	Type	Family
I. Igneous	1. Intrusive (plutonic)	*a.* Granite *b.* Syenite *c.* Diorite *d.* Gabbro *e.* Peridotite
	2. Extrusive (volcanic)	*a.* Rhyolite *b.* Trachyte *c.* Andesite *d.* Basalt and diabase
II. Sedimentary	1. Calcareous	*a.* Limestone *b.* Dolomite
	2. Siliceous	*a.* Shale *b.* Sandstone *c.* Chert (flint)
III. Metamorphic	1. Foliated	*a.* Gneiss *b.* Schist *c.* Amphibolite
	2. Nonfoliated	*a.* Slate *b.* Quartzite *c.* Eclogite *d.* Marble

[1] *Bulletin* 31, U. S. Bureau of Public Roads.

Cost of Tests.—The cost of collecting and testing stone as given in the 1909 Report of the New York State Department of Highways is $8.55 per sample.

The following tables show tests on the more common rocks:

TABLE 44A.—TAKEN FROM BULLETIN 31, UNITED STATES OFFICE OF PUBLIC ROADS

Rock varieties	Per cent[1] wear	Toughness	Hardness	Cementing value	Specific gravity
Granite	3.5	15	18.1	20	2.65
Biotite-granite	4.4	10	16.8	17	2.64
Hornblende-granite	2.6	21	18.3	30	2.76
Augite-syenite	2.6	10	18.4	24	2.80
Diorite	2.9	21	18.1	41	2.90
Augite-diorite	2.8	19	17.7	55	2.98
Gabbro	2.8	16	17.9	29	3.00
Peridotite	4.0	12	15.2	28	3.40
Rhyolite	3.7	20	17.8	48	2.60
Andesite	4.7	11	13.7	189	2.50
Fresh basalt	3.3	23	17.1	111	2.90
Altered basalt	5.3	17	15.6	239	2.75
Fresh diabase	2.0	30	18.2	49	3.00
Altered diabase	2.5	24	17.5	156	2.95
Limestone	5.6	10	12.7	60	2.70
Dolomite	5.7	10	14.8	42	2.70
Sandstone	6.9	26	17.4	90	2.55
Feldspathic sandstone	3.3	17	15.3	119	2.70
Calcareous sandstone	7.4	15	8.3	60	2.66
Chert	10.8	15	19.4	27	2.50
Granite-gneiss	3.8	12	17.7	26	2.68
Hornblende-gneiss	3.7	10	17.1	30	3.02
Biotite-gneiss	3.2	19	17.5	41	2.76
Mica-schist	4.4	10	17.8	30	2.80
Biotite-schist	4.0	..	....	16	2.70
Chlorite-schist	4.2	..	....	24	2.90
Hornblende-schist	3.7	21	16.5	53	3.00
Amphibolite	2.9	10	19.0	29	3.00
Slate	4.7	12	11.5	102	2.80
Quartzite	2.9	19	18.4	17	2.70
Feldspathic quartzite	3.2	17	18.3	21	2.70
Pyroxene quartzite	2.3	27	18.6	17	3.00
Eclogite	2.4	31	17.4	21	3.30
Epodosite	3.6	16	16.0	47	3.03

[1] NOTE.—To convert per cent of wear to French coefficient, see Table on page 506.

TABLE 44B.—FROM ANNUAL REPORT N. Y. STATE HIGHWAY COMM. 1914

County	Number of complete tests	Number of partial tests (no core piece)	Weight pounds per cubic foot	Water absorbed, pounds per cubic foot	French coefficient of abrasion	Hardness	Toughness	Weighted value
Calcareous Sandstone								
Erie	5	..	167	0.65	9.5	12.9	13.4	68
Saratoga	6	..	169	0.31	10.1	15.9	13.8	76
Steuben	4	1	162	1.44	9.4	15.1	13.1	72
Dolomite								
Clinton	6	..	175	0.41	11.9	15.8	12.7	80
Dutchess	4	1	174	0.43	12.4	17.3	11.9	84
Essex	4	..	173	0.42	13.5	16.9	15.8	90
Franklin	4	..	174	0.51	9.5	14.9	21.1	70
Fulton	4	..	176	0.15	11.8	16.1	14.4	82
Herkimer	17	..	173	0.67	8.4	13.1	6.7	58
Monroe	13	2	171	1.07	10.3	14.8	8.2	69
Montgomery	8	..	174	0.39	10.6	14.7	11.3	73
Niagara	11	..	168	1.50	6.5	14.0	7.0	55
Saratoga	8	..	174	0.33	8.6	15.5	9.2	66
St. Lawrence	31	..	174	0.65	10.5	15.7	9.9	73
Washington	6	..	175	0.29	10.7	15.1	10.5	73
Dolomitic Limestone								
Dutchess	8	1	176	0.46	9.0	14.9	10.9	68
Herkimer	4	1	170	0.47	11.3	16.7	8.2	76
Montgomery	8	1	175	0.41	13.0	15.8	12.4	83
Niagara	7	..	166	2.19	9.5	13.1	7.8	63
St. Lawrence	7	..	168	0.38	9.2	16.8	6.8	68
Washington	4	..	175	0.36	13.7	16.1	10.8	84
Wayne	4	..	173	0.59	10.2	15.5	8.7	71
Gabbro								
Essex	46	1	176	0.29	7.6	17.3	6.9	64
Warren	4	..	183	0.37	10.1	17.7	9.8	75
Gneiss								
Clinton	5	..	185	0.27	10.5	17.2	11.3	78
Dutchess	8	1	172	0.58	7.0	17.1	9.1	64
Essex	29	2	176	0.31	8.4	17.1	8.1	68
Franklin	8	..	178	0.50	6.2	16.1	7.8	59
Fulton	12	1	169	0.25	11.1	17.8	11.5	80
Hamilton	11	..	173	0.37	8.2	17.0	5.8	64
Jefferson	26	1	171	0.23	11.1	17.3	12.0	80
Lewis	6	..	167	0.27	9.6	17.9	10.6	75
Orange	7	..	179	0.38	7.1	17.1	6.4	62
Putnam	10	1	172	0.32	8.5	16.6	7.5	66
Saratoga	7	..	180	0.20	10.0	17.0	8.5	72
St. Lawrence	52	..	172	0.27	9.7	17.5	10.2	74
Warren	30	2	173	0.30	7.5	17.3	6.5	64
Washington	4	..	170	0.29	8.5	17.1	10.9	71
Westchester	37	2	171	0.39	8.3	16.9	7.8	67
Granite								
Essex	5	..	171	0.38	7.5	18.0	5.1	64
Franklin	6	..	165	0.31	8.7	17.9	9.4	71
Hamilton	5	..	165	0.36	9.9	18.1	9.0	75
Jefferson	23	1	166	0.23	12.1	18.4	10.1	83
Lewis	8	..	166	0.36	10.9	18.4	9.2	79
Oneida	6	..	166	0.13	10.2	18.9	8.2	77
St. Lawrence	30	..	165	0.25	9.9	18.3	8.1	74
Warren	5	..	165	0.45	7.9	17.9	7.7	67

FROM ANNUAL REPORT N. Y. STATE HIGHWAY COMM. 1914

County	Number of complete tests	Number of partial tests (no core piece)	Weight, pounds per cubic foot	Water absorbed, pounds per cubic foot	French coefficient of abrasion	Hardness	Toughness	Weighted value
Limestone								
Albany	13	7	168	0.60	7.9	14.3	6.4	59
Cayuga	34	6	170	0.49	8.8	14.9	7.8	64
Clinton	14	2	170	0.28	8.2	14.1	5.3	58
Columbia	12	..	170	0.28	9.1	15.3	9.2	67
Erie	9	3	167	0.57	8.1	16.6	8.3	66
Fulton	6	1	168	0.21	7.7	15.5	6.5	60
Genesee	6	3	169	0.26	8.0	15.0	8.2	62
Greene	11	..	169	0.36	11.1	16.4	8.9	75
Herkimer	17	9	169	0.26	8.7	14.8	8.2	64
Jefferson	105	44	169	0.28	7.6	15.1	6.4	59
Lewis	26	20	169	0.32	6.9	14.1	6.2	55
Madison	16	1	169	0.23	8.4	14.7	7.7	62
Monroe	4	..	168	0.27	8.1	14.1	7.4	60
Montgomery	12	2	169	0.24	8.5	15.3	8.0	64
Niagara	11	1	168	0.84	7.1	12.8	6.5	53
Oneida	31	19	169	0.29	7.8	13.8	6.6	58
Onondaga	25	1	170	0.38	8.9	15.7	8.4	67
Ontario	11	..	169	0.39	10.2	15.9	10.2	73
Otsego	7	2	169	0.32	8.1	14.1	6.3	59
Rensselaer	4	1	171	0.21	7.5	15.0	5.3	58
Saratoga	5	..	170	0.24	8.7	13.7	7.0	60
Schoharie	29	2	169	0.34	8.1	14.9	6.7	61
Seneca	7	3	169	0.21	9.4	15.3	7.9	67
Ulster	12	3	170	0.25	8.1	15.6	7.4	63
Warren	5	..	170	0.24	8.9	15.7	7.4	66
Washington	5	3	169	0.34	7.9	15.5	6.9	62
Marble								
Dutchess	4	..	178	0.30	7.3	14.2	6.0	56
Quartzite								
Columbia	16	..	168	0.28	16.5	18.3	17.1	103
Dutchess	8	2	166	0.36	13.5	18.8	11.8	90
Rennsselaer	10	..	166	0.49	12.1	18.7	14.8	89
Washington	12	..	167	0.40	14.6	18.9	16.3	98
Sandstone								
Allegany	8	..	156	2.10	8.4	13.4	9.1	61
Broome	11	..	165	1.29	7.8	12.9	10.5	60
Cayuga	4	1	167	1.16	7.8	12.1	10.5	58
Chenango	15	1	164	1.58	8.7	11.2	10.4	59
Clinton	14	..	163	0.71	11.7	18.5	11.0	83
Delaware	53	2	167	1.45	7.0	12.7	8.5	55
Erie	8	1	159	2.10	6.3	5.1	7.8	37
Franklin	5	..	157	1.06	9.7	17.9	7.1	72
Greene	6	..	169	0.62	8.6	14.5	8.1	63
Herkimer	4	..	160	2.50	10.9	16.4	10.7	76
Jefferson	8	..	156	1.46	8.3	16.2	6.3	64
Livingston	4	..	160	3.02	8.8	9.6	8.8	54
Madison	5	..	163	2.15	9.9	13.9	8.6	66
Niagara	7	..	158	1.78	9.0	16.4	8.2	68
Orleans	8	..	155	2.18	11.8	14.4	8.1	72
Otsego	21	1	162	1.75	8.4	11.9	9.6	59
Saratoga	5	..	163	0.36	10.7	18.0	8.7	77
Schoharie	6	3	165	1.21	9.4	15.2	11.7	70
Schuyler	4	..	162	2.14	8.1	11.6	10.6	58
Seneca	5	..	165	0.86	11.0	13.9	15.8	77
Steuben	22	3	157	2.79	8.3	9.3	10.0	54
St. Lawrence	16	..	159	0.79	10.0	17.8	7.2	73
Sullivan	30	4	164	1.26	6.5	14.9	8.2	58
Ulster	8	..	166	0.64	8.0	14.3	8.1	61
Wyoming	7	..	159	2.54	6.0	5.1	7.9	36

FROM ANNUAL REPORT N. Y. STATE HIGHWAY COMM. 1914.—*Continued*

County	Number of complete tests	Number of partial tests (no core piece)	Weight, pounds per cubic foot	Water absorbed, pounds per cubic foot	French coefficient of abrasion	Hardness	Toughness	Weighted value
Sandy Grit								
Albany	5	..	167	0.75	7.5	13.2	7.2	56
Columbia	12	..	168	0.32	10.7	15.9	11.7	76
Dutchess	10	2	168	0.57	8.1	16.2	11.5	68
Greene	13	..	169	0.48	7.1	15.6	9.5	62
Montgomery	4	..	166	1.39	10.1	11.3	11.8	65
Rensselaer	10	..	169	0.44	9.1	15.9	9.4	69
Saratoga	5	..	168	0.99	11.8	15.2	11.9	78
Schenectady	4	..	165	1.10	9.2	14.6	9.5	66
Ulster	7	..	169	0.59	7.5	13.8	10.2	60
Syenite								
Essex	7	..	184	0.52	7.7	17.1	6.7	64
Franklin	4	..	171	0.45	10.1	18.3	8.0	75
Herkimer	13	..	174	0.16	12.5	18.0	11.6	85
Jefferson	7	..	176	0.34	12.4	18.1	14.5	88
Trap								
Rockland	12	..	183	0.39	13.2	17.6	1.64	91

The following quotation from *Bulletin* 31 O. P. R. and R. E. describes the characteristics of the three groups:

Igneous Rocks.—All rocks of the igneous class are presumed to have solidified from a molten state, either upon reaching the earth's surface or at varying depths beneath it. The physical conditions, such as heat and pressure, under which the molten rock magma consolidated, as well as its chemical composition and the presence of included vapors, are the chief features influencing the structure. Thus, we find the deep-seated, plutonic rocks coarsely crystalline with mineral constituents well defined, as in case of granite rocks, indicating a single, prolonged period of development, whereas the members of the extrusive or volcanic types, solidifying more rapidly at the surface, are either fine-grained or frequently glassy and vesicular, or show a porphyritic structure. This structure is produced by the development of large crystals generally by a recurrence of mineral growth during the effusive period of magmatic consolidation.

In the arrangement of the rock families from a mineralogical standpoint it will be noted that the plutonic rock types, granite, syenite, and diorite, are represented by their equivalent extrusive varieties, rhyolite and andesite, and that diabase has been included, somewhat arbitrarily, with basalt, as a volcanic representative of gabbro. These latter rocks are of special interest, owing to their wide distribution and general use in road construction. They occur in the forms of dykes, intruded sheets, or volcanic flows, and vary in structure from glassy-porphyritic (typical basalt) to wholly crystalline and even granular (diabase). Their desirable qualities for road-building are caused to a large extent by a peculiar interlocking of the mineral components (ophitic structure), yielding a very tough and resistant material well qualified to sustain the wear of traffic.

Igneous rocks vary in color from the light gray, pink, and brown of the acid granites, syenites, and their volcanic equivalents (rhyolite, andesite, etc.) to the dark steel-gray or black of the basic gabbro, peridotite, diabase, and basalt. The darker varieties are commonly called trap. This term is in very general use and is derived from trappa, Swedish for stair, because rocks of this kind on cooling frequently break into large tabular masses, as may be seen in the exposures of diabase on the west shore of the Hudson River from Jersey City to Haverstraw.

Sedimentary Rocks.—The sedimentary rocks as a class represent the consolidated products of former rock disintegration, as in the case of sandstone, conglomerate, shale, etc., or they have been formed from an accumulation of organic remains chiefly of a calcareous nature, as is true of limestone and dolomite. These fragmental or elastic materials have been transported by water and deposited mechanically in layers on the sea or lake bottoms

producing a very characteristic bedded or stratified structure in many of the resulting rocks.

In the case of certain colitic and travertine limestones, hydrated iron oxides, siliceous deposits, such as geyserite, opal, flint, chert, etc., the materials have been formed chiefly by chemical precipitation and show generally a concentric or colloidal structure.[1] Oolitic and pisolitic limestones consist of rounded pealike grains of calcic carbonate held together by a calcareous cement. Travertine is the so-called "onyx marble" of Mexico and Arizona. It is a compact rock, concentric in structure and formed by the precipitation of carbonate of lime from the waters of springs and streams.

Loose or unconsolidated rock debris of a prevailing siliceous nature comprise the sands, gravels, finer silts and clays (laterite, adobe, loess, etc.). Shell sands and marls, on the other hand, are mainly calcareous, and are formed by an accumulation of the marine shells and of lime-secreting animals. Closely associated with the latter deposits in point of origin are the beds of diatomaceous or infusorial earth composed almost entirely of the siliceous casts of diatoms, a low order of seaweed or algae.

This unconsolidated material may pass by imperceptible gradations into representative rock types through simple processes of induration. Thus clay becomes shale, and that in turn slate, without necessarily changing the chemical or mineralogical composition of the original substance.

Such terms as flagstone, freestone, brownstone, bluestone, graystone, etc., are generally given to sandstones of various colors and composition, while puddingstone, conglomerate, breccia, etc., apply to consolidated gravels and coarse feldspathic sands.

The calcareous rocks are of many colors, according to the amount and character of the impurities present.

Metamorphic Rocks.—Rocks of this class are such as have been produced by prolonged action of physical and chemical forces (heat, pressure, moisture, etc.) on both sedimentary and igneous rocks alike. The foliated types (gneiss, schist, etc.) represent an advanced stage of metamorphism on a large scale (regional metamorphism), and the peculiar schistose or foliated structure is due to the more or less parallel arrangement of their mineral components. The non-foliated types (quartzite, marble, slate, etc.) have resulted from the alteration of sedimentary rocks without materially affecting the structure and chemical composition of the original material.

Rocks formed by contact metamorphism and hydration, such as hornfels, pyroxene marble, serpentine, serpentineous limestone, etc., are of great interest from a petographical standpoint, but are rarely of importance as road materials.

The color of metamorphic rocks varies between gray and white of the purer marbles and quartzites to dark gray and green of the gneisses, schists, and amphibolites. The green varieties are commonly known as greenstones, or greenstone schists.

Interpretation of Tests.—It has been found impractical to specify definite qualities of stone for use in macadam highways. Economy and practical engineering demand that all available sources be considered. Tests are made to determine the relative qualities of stone from these different sources and the results used as a guide for selection.

In the work of the New York State Highway Commission all tests are tabulated geographically, using a county as a unit. Table 44B is compiled from the records of this department. It will be noted that comparisons are made in different classifications only, as it is considered that conclusions should not be drawn from a comparison of tests procured from materials having different origins and composed of different minerals.

For the purpose of ready comparison, there has been introduced a figure known as the "weighted value." (See last column of table.) This is computed by giving relative weights of three to the French coefficient,

[1] G. P. Merill, "Rocks, Rock Weathering, and Soils," 1897, pp. 104–114.

two to the hardness, one to the toughness values and adding the three together. These relative weights were determined from a consideration of the amount of material used in the different tests and the personal equation of running them.

By consulting these tables the available rocks of different classifications in various sections throughout New York State can be determined readily, and as new tests are completed they are compared with good average material from that section.

Conclusions.—Trap (diabase), granite, gneiss, quartzite, sandstone and limestone are the most common rocks and when found in a good state of preservation make good surfacing materials.

As generally found, trap is uniform in hardness and toughness, making an excellent material for use in top course.

Granite and gneiss, where they occur with hornblende replacing a large percentage of the quartz, make an excellent surfacing stone.

Quartzites when found in good state of preservation are hard and tough. They should not be confused with crystalline quartz which is hard but brittle.

Sandstones are extremely variable and only the better varieties should be used.

Limestones range from the fine-grained dense products which are hard and tough to the coarse-grained soft products which are not suitable for surfacing.

2. Screenings.—Screenings act as a filler and binder for waterbound macadam and as a partial filler for bituminous macadam. For use in waterbound construction the main mineral constituent is the most essential feature to be considered as this must be a material that will form a binder and "puddle" readily when subjected to the action of a road roller and water.

Limestone screenings have proved the most efficient as a binder in waterbound construction, although trap and some other igneous rocks can be bound with their own dust by repeated puddling. Screenings consisting mainly of quartz have never been used successfully in waterbound construction except by the addition of some limestone screenings. The use of a percentage of clay or loam as a binder is not advisable except where the cost of limestone screenings would be prohibitive.

Laboratory methods for testing the cementing power of rock powders are available but the results obtained are erratic and undependable.

In plain waterbound roads it is often necessary to mix some limestone screenings, fine sandy loam, or even a small percentage of clay loam with trap, granite, sandstone, quartzite, or gneiss screenings to get a good bond and prevent raveling in dry weather.

3. Bottom Course Macadam Stone.—As the bottom stone simply spreads the wheel loads transmitted through the top course and is not

directly subjected to the traffic action, almost any stone that breaks into cubical irregular shapes that will not air or water slake and that is hard enough to stand the action of the roller during construction will be satisfactory.

Any of the materials listed above in Table 44 except shale and slate can be used, provided that they are not rotten from long exposure in the air. The different available varieties are usually tested in the same manner as for top stone in order to pick the best. Acid blast furnace crushed slag makes an excellent bottom course but is not uniform enough for top course.

4. Fillers.—Fillers are used in the bottom course to fill the voids between the crushed stone and to prevent rocking or sidewise movement of the larger pieces.

They should be easy to manipulate in placing, should not soften when wet, or draw water up from the subgrade by capillary action.

The materials most used for macadam bottom are

Coarse sandy loam.
Coarse sand.
Gravel with large excess of fine material.
Stone screenings.

The fitness of the material can be determined by inspection and by wetting a handful; if it gets sticky or works into a soft mud it should not be used.

Boulder or Telford Base Fillers.—This type of construction requires the use of clean hard gravel fairly coarse (at least 40 per cent retained on ¼-in. screen) with not over 15 per cent of loam or silt content or broken stone, slag or chert. If broken stone is used the voids of the stone must be filled with the same class of sand or screenings as stipulated for macadam bottom.

5. Vitrified Brick.—Bricks must withstand the same destructive agencies as described for top stone. They must be uniform in size, tough, hard, dense, evenly burned, and, on account of their peculiar shape, must have a high resistance against rupture. These properties are tested by the standard methods adopted by the American Brick Manufacturers' Association described below.

It should be understood that bricks suitable for paving are manufactured in a different way and of different materials than ordinary building bricks.

The materials for molding any paving brick must be of a peculiar character which will not melt and flow when exposed to an intense heat for a number of days but will gradually fuse and form vitreous combinations throughout while still retaining its form.

The resulting brick must be a uniform block of dense texture in which the original stratification and granulation of the clay has been wholly lost by fusion which has stopped just short of melting the clay and forming glass.

The clay while fusing must shrink equally throughout, thus causing the brick to be without laminations or of any exterior vitrified crust differing from the interior.[1]

The great majority of paving brick are made in Ohio, Illinois, Indiana, Pennsylvania, West Virginia, and New York. They are classed as shale or fire-clay brick.

Brick.—Paving brick shall be reasonably perfect in shape—shall be free from marked warping or distortion, and shall be uniform in size, so as to fit closely together and to make a smooth pavement. All brick shall be homogeneous in texture and free from laminations and seams. All brick shall be evenly burned and thoroughly vitrified.

Soft, brittle, cracked, or spalled brick, or brick kiln-marked to a height or depth of over $\frac{3}{64}$ in. will be rejected.

If brick have rounded corners, the radius shall not be greater than $\frac{1}{16}$ in.

Brick must have not less than 2 nor more than 4 vertical lugs or projections not more than $\frac{1}{2}$ in. wide, on 1 side of each brick, the total area of all lugs being not more than 3 sq. in., so that when laid there shall be a separation between the bricks of at least $\frac{1}{8}$ in. and not more than $\frac{1}{4}$ in. The imprint, or name of the brick, or maker, if used, shall be by means of recessed and not by raised letters. The two ends of the brick shall have a semi-circular groove, with a radius of not less than $\frac{1}{8}$ in. and not more than $\frac{1}{4}$ in. Grooves shall be so located that when the bricks are laid together the grooves shall match perfectly; grooves shall be horizontal when brick is laid in pavement.

All brick shall not be less than $3\frac{1}{4}$ by $3\frac{3}{4}$ by $8\frac{1}{2}$ in. nor more than $3\frac{1}{2}$ by 4 by 9 in. in size.

All brick shall be subject to tests for abrasion and impact, for absorption according to the standard methods prescribed by the National Brick Manufacturers' Association, as follows:

The Rattler.—The machine shall be of good mechanical construction, self-contained, and shall conform to the following details of material and dimensions, and shall consist of barrel, frame and driving mechanism as herein described.

The Barrel.—The barrel of the machine shall be made up of the heads, headliners and staves.

The heads shall be cast with trunnions in 1 piece. The trunnion bearings shall not be less than two and one-half ($2\frac{1}{2}$) inches in diameters or less than six (6) inches in length.

The heads shall not be less than three-fourths ($\frac{3}{4}$) inch thick nor more than seven-eighths ($\frac{7}{8}$) inch. In outline they shall be a regular fourteen-sided (14) polygon inscribed in a circle twenty-eight and three-eighths ($28\frac{3}{8}$) inches in diameter. The heads shall be provided with flanges not less than three-fourths ($\frac{3}{4}$) inch thick and extending outward two and one-half ($2\frac{1}{2}$) inches from the inside face of head to afford a means of fastening the staves. The flanges shall be slotted on the outer edge, so as to provide for two (2) three-fourths ($\frac{3}{4}$) inch bolts at each end of each stave, said slots to be thirteen-sixteenths ($\frac{13}{16}$) inch wide and two and three-fourths ($2\frac{3}{4}$) inches center to center. Under each section of the flanges there shall be a brace three-eights ($\frac{3}{8}$) inch thick and extending down the outside of the head not less than two (2) inches. Each slot shall be provided with recess for bolt head, which shall act to prevent the turning of the same. There shall be for each head a cast-iron headliner one (1) inch in thickness and conforming to the outline of the head, but inscribed in a circle twenty-eight and one-eighth ($28\frac{1}{8}$) inches in diameter. This liner or wear plate shall be fastened to the head by seven (7) five-eights ($\frac{5}{8}$) inch cap screws, through the head from the outside. These wear plates, whenever they become worn down one-half ($\frac{1}{2}$) inch below their initial surface level, at any point of their surface, must be replaced with new. The metal of which these wear plates are to be composed shall be what is known as hard machinery iron, and must contain not less than one (1) per cent of combined carbon. The faces of the polygon must be smooth and give uniform bearing for the staves. To secure the desired uniform bearing the faces of the head may be ground or machined.

The Staves.—The staves shall be made of six (6) inch medium steel structural channels twenty-seven and one-fourth ($27\frac{1}{4}$) inches long and weighing fifteen and five-tenths (15.5) pounds per lineal foot.

[1] JUDSON, "Roads and Pavements," page 87.

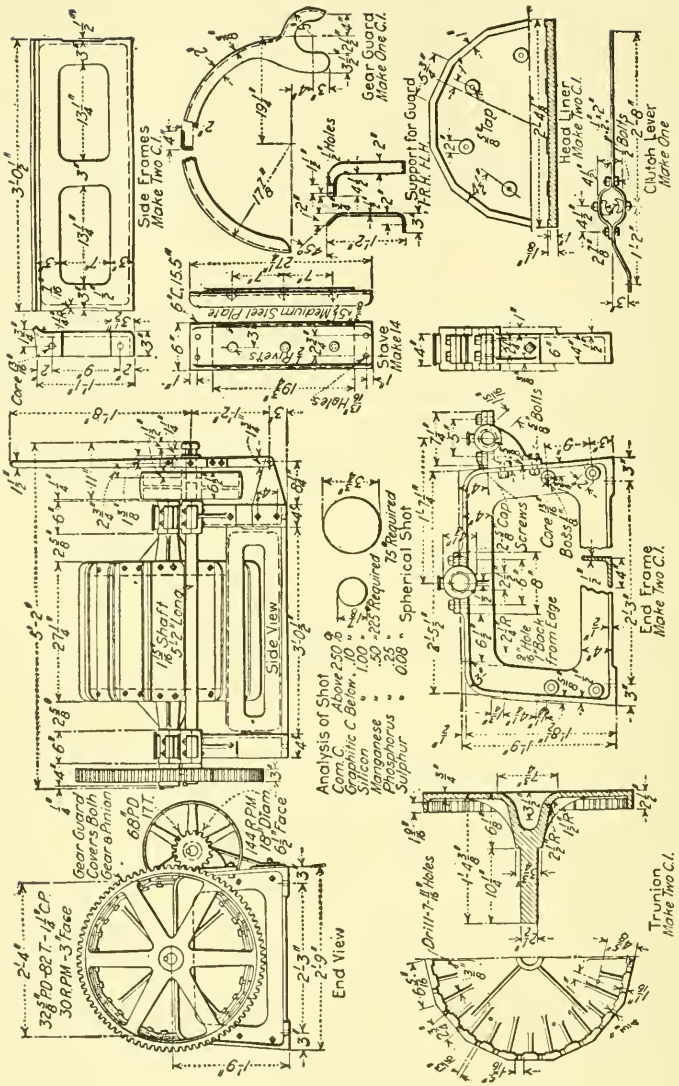


FIG. 205.—Brick rattler.

The channels shall be drilled with holes thirteen-sixteenths ($1\frac{3}{16}$) inch in diameter, two (2) in each end, for bolts to fasten same to head, the center line of the holes being one (1) inch from either end and one and three-eighths ($1\frac{3}{8}$) inches either way from the longitudinal center line.

The space between the staves will be determined by the accuracy of the heads, but must not exceed five-sixteenths ($\frac{5}{16}$) inch. The interior or flat side of each channel must be protected by a lining or wear plate three-eighths ($\frac{3}{8}$) inch thick by five and one-half ($5\frac{1}{2}$) inches wide by nineteen and three-quarters ($19\frac{3}{4}$) inches long. The wear plate shall consist of medium steel plate, and shall be riveted to the channel by three (3) one-half ($\frac{1}{2}$) inch rivets, one of which shall be on the center line both ways and the other two on the longitudinal center line and spaced seven (7) inches from the center each way. The rivet holes shall be countersunk on the face of the wear plate and the rivets shall be driven hot and chipped off flush with the surface of the wear plate. These wear plates shall be inspected from time to time, and if found loose shall be at once riveted, but no wear plate shall be replaced by a new one except as the whole set is changed. No set of wear plates shall be used for more than one hundred and fifty (150) tests under any circumstances. The record must show the date when each set of wear plates goes into service and the number of tests made upon each set.

The staves when bolted to the heads shall form a barrel twenty (20) inches long, inside measurement, between wear plates. The wear plates of the staves must be so placed as to drop between the wear plates of the heads. These staves shall be bolted tightly to the heads by four (4) three-fourths ($\frac{3}{4}$) inch bolts, and each bolt shall be provided with lock nuts, and shall be inspected at not less frequent intervals than every fifth (5th) test and all nuts kept tight. A record shall be made after each such inspection, showing in what condition the bolts were found.

The Frame and Driving Mechanism.—The barrel should be mounted on a cast-iron frame of sufficient strength and rigidity to support same without undue vibration. It should rest on a rigid foundation and be fastened to same by bolts at not less than four (4) points.

It should be driven by gearing whose ratio of driver to driven should not be less than one (1) to four (4). The counter shaft upon which the driving pinion is mounted should not be less than one and fifteen-sixteenths ($1\frac{15}{16}$) inches in diameter, with bearings not less than eighteen (18) inches in diameter and six and one-half ($6\frac{1}{2}$) inches in face. A belt of six (6) inch double-strength leather, properly adjusted, so as to avoid unnecessary slipping, should be used.

(As a part of this publication will be found a complete working drawing of a machine which will meet the above specifications and requirements.)

The Abrasive Charge.—(*a*) The abrasive charge shall consist of two sizes of cast-iron spheres. The larger size shall be three and seventy-five-hundredths (3.75) inches in diameter when new and shall weigh when new approximately seven and five-tenths (7.5) pounds (3.40 kilos) each. Ten shall be used.

These shall be weighed separately after each ten (10) tests, and if the weight of any large shot falls to seven (7) pounds (3.175 kilos) it shall be discarded and a new one substituted; provided, however, that all of the large shot shall not be discarded and substituted by new ones at any single time, and that so far as possible the large shots shall compose a graduated series in various stages of wear.

The smaller size spheres shall be when new one and eight hundred seventy-five-thousandths (1.875) inches in diameter and shall weigh not to exceed ninety-five-hundredths (0.95) pounds (0.430 kilos) each. Of these spheres so many shall be used as will bring the collective weight of the large and small spheres most nearly to three hundred (300) pounds, provided that no small sphere shall be retained in use after it has been worn down so that it will pass a circular hole one and seventy-five-hundredths (1.75) inches in diameter, drilled in a cast-iron plate one-fourth ($\frac{1}{4}$) inch in thickness or weigh less than seventy-five-hundredths (0.75) pounds (or 0.34 kilos). Further, the small spheres shall be tested by passing them over such an iron plate drilled with such holes, or shall be weighed after every ten (10) tests, and any which pass through or fall below specified weight, shall be replaced by new spheres, and provided, further, that all of the small spheres shall not be rejected and replaced by new ones at any one time, and that so far as possible the small spheres shall

compose a graduated series in various stages of wear. At any time that any sphere is found to be broken or defective it shall at once be replaced.

(*b*) The iron composing these spheres shall have a chemical composition within the following limits:

Combined carbon—Not less than 2.50 per cent
Graphitic carbon—Not more than 0.10 per cent
Silicon—Not more than 1 per cent
Manganese—Not more than 0.50 per cent
Phosphorus—Not more than 0.25 per cent
Sulphur—Not more than 0.08 per cent

For each new batch of spheres used the chemical analysis must be furnished by the maker, or be obtained by the user, before introduction into the charge, and unless the analysis meets the above specifications, the batch of spheres shall be rejected.

The Brick Charge.—The number of brick per charge shall be ten (10) for all bricks of the so-called "block size" whose dimensions fall between from eight (8) to nine (9) inches in length, three (3) and three and three-fourths (3¾) inches in breadth and three and three-fourth (3¾) and four and one-fourth (4¼) inches in thickness. No block should be selected for test that would be rejected by any other requirements for the specifications.

The brick shall be clean and dried for at least three (3) hours in a temperature of one hundred (100) degrees Fahr. before testing.

Speed and Duration of Revolution.—The rattler shall be rotated at a uniform rate of not less than twenty-nine and one-half (29½) nor more than thirty and one-half (30½) revolutions per minute, and eighteen hundred (1,800) revolutions shall constitute the standard test.

A counting machine shall be attached to the rattler for counting the revolutions. A margin of not to exceed ten (10) revolutions will be allowed for stopping. Only one (1) start and stop per test is regular and acceptable.

The Results.—The loss shall be calculated in percentage of the original weight of the dried brick composing the charge. In weighing the rattled brick any piece weighing less than one (1) pound shall be rejected.

Records.—(*a*) The operator shall keep an official book, in which the alternate pages are perforated for removal. The record shall be kept in duplicate, by use of a carbon paper between the first and second sheets, and when all entries are made and calculations are completed the original record shall be removed and the carbon duplicate preserved in the book. All calculations must be made in the space left for that purpose in the record blank, and the actual figures must appear. The record must bear its serial number and be filled out completely for each test, and all data as to dates of inspection and weighing of shot and replacement of worn-out parts must be carefully entered, so that the records remaining in the book, constitute a continuous one. In event of further copies of a record being needed, they may be furnished on separate sheets, but in no case shall the original carbon copy be removed from the record book.

REPORT OF STANDARD RATTLER TEST OF PAVING BRICKS

IDENTIFICATION DATA SERIAL (—)

Name of the firm furnishing sample
Name of the firm manufacturing sample
Street or job which sample represents
Brands or marks on the brick
Quantity furnished — Drying treatment
Date received — Date tested
Length — Breadth — Thickness

STANDARDIZATION DATA

Number of charges treated since last inspection.

Weight of Charge (After Standardization)	Condition of Locknuts on Staves	Condition of Seales
10 Large spheres		
Small spheres		
Total		

Number of charges tested since stave linings were renewed
Repairs (Note any repairs affecting the condition of the barrel)

RUNNING DATA

Time Readings			Revolution Counter Readings	Running notes, Stops, etc.
Hours	Minutes	Seconds		
Beginning of Test				
Final Reading				

WEIGHTS AND CALCULATIONS

Initial Weight of 10 Bricks.....
Final Weight of same.....
Loss of Weight.....
Number of broken bricks and remarks on same

Percentage Loss
(Note—The Calculation Must Appear)

I certify that the foregoing test was made under the specifications of and is a true record.

Date

Signature of (Tester).....
Location of Laboratory.

Any brick which loses twenty-four (24) per cent or more in the rattler, or increases more than 3½ per cent in weight or less than ½ of 1 per cent in the absorption test, will be rejected.

6. Bituminous Binders.—The subject of bitumens is an intricate one and the reader is referred to the works of Clifford Richardson, Prevost Hubbard, and others, for detailed information, as a book of this character can given only an outline.

There are a number of dust preventives and road binders on the market which depend for their effectiveness on a bituminous binding base. The term bitumen is applied to a great many substances. Hubbard arbitrarily defines bitumens as "consisting of a mixture of native or pyrogenetic hydrocarbons and their derivatives, which may be gaseous, liquid, a viscous liquid, or solid, but if solid melting more or less readily upon the application of heat and soluble in chloroform, carbon bisulphide, and similar solvents."[1]

The bitumens may be classified as native and artificial. The native bituminous materials, that are used in road work, are the asphaltic and semi-asphaltic oils (dust layers), Malthas (the binding base of Rock Asphalts), Trinidad, Bermudez California, and Cuba asphalts, Gilsonite, and Grahamite (which, however, are too brittle in their natural state and require fluxing with a suitable residual oil before they can be used

[1] "Dust Preventives and Road Binders." John Wiley & Sons.

as binders). The natural asphalts are refined to remove water and any objectionable amount of impurities by heating until the gases are driven off, skimming the vegetable matter which rises to the surface, and removing the mineral constituents which fall to the bottom.

The artificial bituminous materials are derived by the destructive distillation of coal, or by fractional distillation of crude coal tars, or the native petroleum oils. They comprise the crude coal and water gas tars, the refined tars, the residual oils and semi-solid binders derived from the petroleum oils. They vary greatly in consistency and binding power.

The following material is briefed from *Bulletin* 34, United States Office of Public Roads: The light oils and tars have a relative small percentage of bituminous base and are effective only so long as it retains its binding power; the more permanent binders contains a larger percentage of bitumen; these are the heavy oils and semi-solids.

ARTIFICIAL BITUMENS

Crude Tars.—Coke ovens and gas plants produce most of the coal tars in use. These tars contain various complex combinations of carbon, hydrogen, and oxygen and small amounts of nitrogen and sulphur. They vary in composition according to the material from which they are made and the temperature at which they are distilled. The percentage of free carbon ranges from 5 to 35 per cent, and the bitumen from 60 to 95 per cent depending on the temperature of manufacture. Tars produced at high temperatures contain free carbon in excess which weakens their binding power; they, also, contain a large amount of anthracine and naphthalene, two useless materials from the standpoint of road work. Tars produced at low temperatures are to be preferred. Coke tar is low temperature tar; gas tar is high temperature tar.

TABLE 45A.—SPECIFIC GRAVITY AND COMPOSITION OF TAR PRODUCTS
Table from *Bulletin* 34, United States Office of Public Roads

Kind of tar	Specific gravity	Ammoniacal water, per cent	Total light oils to 170°C., per cent	Total dead oils 170° 270°C., per cent	Residue (by difference), per cent
Water-gas tar	1.041	2.4	*a*21.6	*b*52.0	*e*24.0
Crude coal tar	1.210	2.0	*d*17.2	*e*26.0	*f*54.8
Refined coal tar	1.177	0.0	*b*12.8	*g*47.6	*f*39.6

a. Distillate, mostly liquid.
b. Distillate, all liquid.
c. Pitch, very brittle.
d. Distillate, mostly solid.
e. Distillate, one-half solid.
f. Pitch, hard and brittle.
g. Distillate, one-third solid.

Table 46 gives a more up-to-date analysis of the coal tars on the market.

The tests and detailed requirements for light, medium and heavy bitumens are given on pages 529 and 551.

Refined Tars.—Much of the road tar is refined tar—that is, it has been subjected to fractional distillation to remove the valuable volatile compounds. The residuum from this process is a thick viscous material known as coal-tar pitch, and if the crude tar from which it is obtained was produced at a low temperature it is nearly pure bitumen; the dead oils obtained from the distillation are of little value and are often run back into the pitch, which makes it liquid when cold. The following table gives the approximate composition of water-gas tar, crude coal tar, and refined tar.

If the tar is used as a temporary dust-layer only, it should be a low-temperature, dehydrated tar, liquid when cold. If used as a more permanent binder and applied hot, it should have a larger percentage of pitch, should contain no water, and be free from an excessive amount of free carbon. If used as a mastic in bituminous macadam, it should contain a high percentage of pitch and be free from the defects mentioned.

Natural Bitumens and Artificial Residual Oils and Semi-solids.—Mineral oils can be classed as paraffin petroleums, mixed paraffin and asphaltic petroleums, and asphaltic petroleums. The relative value of oils as a source of supply for road materials depends on their percentage of asphaltic residue. The eastern oils found in New York, Pennsylvania, West Virginia, etc., are paraffin petroleums; the western oils vary from light to heavy asphaltic petroleums, and the southern oils have a mixed paraffin and asphaltic base.

The crude petroleum is refined by fractional distillation to obtain its valuable products, such as kerosene, etc. The character of the residue depends, as for the tars, on the crude

TABLE 45B.—RESULTS OF TESTS OF CRUDE PETROLEUM

Tables from Bulletin No. 34, United States Office of Public Roads

Kinds of Oil	Specific gravity	Flash point, degrees Centigrade	Volatility at 110°C. 7 hours, per cent	Volatility at 160°C. 7 hours, per cent	Volatility at 205°C. 7 hours, per cent	Residue, per cent
Pennsylvania, paraffin	0.801	(*a*)	47.3	58.0	68.0	*b*32.0
Texas, semi-asphaltic	0.904	43	20.0	27.0	49.0	*c*51.0
California, asphaltic	0.939	26	....	....	*d*42.7	*e*57.3

a. Ordinary temperature.
b. Soft.
c. Quick flow.
d. Volatility at 200°, 7 hour.
e. Soft maltha; sticky.

TABLE 45C.—RESULTS OF PETROLEUM RESIDUUM

Kinds of oil	Specific gravity	Flash point, degrees Centigrade	Volatility at 200°C. 7 hour, per cent	Residue, per cent	Solid paraffin, per cent	Fixed carbon, per cent
Pennsylvania, paraffin	0.920	186	14.2	*a*85.8	11.0	3.0
Texas, semi-asphaltic	0.974	214	6.2	*a*93.8	1.7	3.5
California, asphaltic	1.006	191	17.3	*a*82.7	0.0	6.0

a. Soft.

TABLE 46.—CIRCULAR NO. 97,
Analysis of crude coke-oven tars pro-

Serial No.	General information: Company and location	General information: Type of oven	Maximum temperature of firing retorts
5126	Solvay Process Co., Syracuse, N. Y.	Sement-Solvay	1,650–1,450°C.
5123	Semet-Solvay Co., Pennsylvania Steel Co., Steelton, Pa.	Semet-Solvay	1,050–1,450°C.
5124	Semet-Solvay Co., National Tube Co., Benwood, W. Va.	Semet-Solvay	1,050–1,450°C.
5137	Semet-Solvay Co., Milwaukee Coal & Gas Co., Milwaukee, Wis.	Semet-Solvay	1,050–1,450°C.
5121	Semet-Solvay Co., Pennsylvania Steel Co., Lebanon, Pa.	Semet-Solvay	1,050–1,450°C.
5125	By-Products Coke Corporation, South Chicago, Ill.	Semet-Solvay	1,050–1,450°C.
5128	Semet-Solvay Co., Detroit, Mich.	Semet-Solvay	1,050–1,450°C.
5200	Semet-Solvay Co., Empire Coke Co., Geneva, N. Y.	Semet-Solvay	1,050–1,450°C.
5189	Semet-Solvay Co., Dunbar Furnace Co., Dunbar, Pa.	Semet-Solvay	1,050–1,450°C.
5160	Semet-Solvay Co., Central Iron & Coal Co., Tuscaloosa, Ala.	Semet-Solvay	1,250°C.
5074	Philadelphia Suburban Gas & Electric Co., Chester, Pa.	Semet-Solvay	1,050°C.
5081	Semet-Solvay Co., Ensley, Ala.	Semet-Solvay	1,250°C.
5095	The N. E. Gas & Coke Co., Everett, Mass.	Otto Hoffman[1]	1,100°C.
5083	Lackawanna Steel Co., Lackawanna Iron & Steel Co., Lebanon, Pa.	Otto Hoffman	1,000°C. (1,800°F.)
5159	Dominion Tar & Chemical Co., Sydney, Nova Scotia.	Otto Hoffman	[2]
5107	Hamilton Otto Coke Co., Hamilton, Ohio.	Otto Hoffman	1,111°C. (2,000°F.)
5086	Carnegie Steel Co., South Sharon, Pa.	United Otto	1,666°C. (3,000°F.)
5078	Maryland Steel Co., Sparrows Point, Md.	United Otto	1,333°C. (2,400°F.)
5087	Citizens' Gas Co., Indianapolis, Ind.	United Otto	1,222°C. (2,200°F.)
5109	Pittsburg Gas & Coke Co., The United Coke & Gas Co., Glassport, Pa.	United Otto	[2]
5122	Zenith Furnace Co., Duluth, Minn.	United Otto	1,222–1,277°C. 2,200–2,300°F.
5188	Illinois Steel Co., Joliet, Ill.	Koppers	1,444°C. (2,600°F.)
5404	Illinois Steel Co., Indiana Steel Co., Gary, Ind.	Koppers	1,100°C.
5108	Camden Coke Co., Camden, N. J.	Otto Hoffman United Otto	1,000°C. (1,800°F.) 1,222°C. (2,200°F.)
5127	Cambria Steel Co., Johnstown, Pa.	Otto Hoffman United Otto	1,111°C. (2,000°F.) 1,111°C. (2,000°F.)
5089	Lackawanna Steel Co., Buffalo, N. Y.	United Otto Rothberg	1,000°C. (1,800°F.) 1,000°C. (1,800°F.)

U. S. Office of Public Roads
duced in the United States and Canada

Answers to questions			Examination			
Maximum temperature to which coal is brought	Specific gravity of crude tar	Per cent of free carbon in tar	Specific gravity of tar, 25°C.	Per cent of free carbon	Per cent of ash	Per cent soluble in CS_2, including H_2O
950–1,150°C.	1.12–1.21	3–12	1.195	7.76	0.12	92.12
950–1,150°C.	1.12–1.21	3–12	1.206	8.77	0.07	91.16
950–1,150°C.	1.12–1.21	3–12	1.176	7.14	0.04	92.82
950–1,150°C.	1.12–1.21	3–12	1.168	6.10	0.05	93.85
950–1,150°C.	1.12–1.21	3–12	1.173	4.71	0.06	95.23
950–1,150°C.	1.12–1.21	3–12	1.191	7.49	0.03	92.48
950–1,150°C.	1.12–1.21	3–12	1.169	6.56	0.11	93.33
950–1,150°C.	1.12–1.21	3–12	1.159	6.07	0.08	93.85
950–1,150°C.	1.12–1.21	3–12	1.181	8.85	0.02	91.13
1,150°C.	1.17	5.72	1.159	5.05	0.02	94.93
1,000°C.	1.16 (20°C.)	.....	1.141	3.96	0.05	95.99
1,150°C.	1.17 (15°C.)	8	1.175	6.90	0.06	93.04
[1]1,200°C.	1.17	8–10	1.160	13.94	0.00	86.06
1,000°C. (1,800°F.)	1.10	16–24	1.214	14.05	0.13	85.82
[2]	1.170	10–15	1.143	10.81	0.05	89.14
1,111°C. (2,000°F.)	1.14	[6]16.0	1.160	8.37	0.06	91.57
1,444°C. (2,600°F.)	1.2	7.09–10.64	1.191	7.89	0.03	92.08
1,222°C. (2,200°F.)	[3]1.19	[3]8–10	1.179	8.49	0.03	91.48
1,222°C. (2,200°F.)	1.14–1.15	4–5	1.133	5.21	0.07	94.72
[2]	(50°F.) 1.207 (10°C.)	16.59	1.176	10.53	0.04	89.43
[2]	[2]	[2]	1.195	12.18	0.05	87.77
1,388°C. (2,500°F.)	1.16–1.20	12–15	1.171	3.89	0.06	96.05
880–950°C.	[4]1.174 1.169	4.35	1.169	2.73	0.04	97.23
833°C. (1,500°F.) 1,055°C. (1,900°F.)	1.20–1.30 [5](1.221)	7–9 [5](7.3)	1.182	11.30	0.06	88.64
[1]1,111°C. (2,000°F.) [1]1,111°C. (2,000°F.)	1.12	[1]15	1.211	12.40	0.16	87.44
1,000°C. (1,800°F.) 1,000°C. (1,800°F.)	1.16	16–24	1.210	16.80	0.00	83.20

TABLE 46

Serial No.	Company and location	Examination, public roads			
		Distillation results			
		Water		Light oils up to 110°C.	
		Per cent by volume	Per cent by weight	Per cent by volume	Per cent by weight
5126	Solvay Process Co., Syracuse, N. Y.	1.0	0.8	[8]0.3	0.3
5123	Semet-Solvay Co., Pennsylvania Steel Co., Steelton, Pa.	1.0	0.8	0.4	0.3
5124	Semet-Solvay Co., National Tube Co., Benwood, W. Va.	1.1	1.0	1.9	1.5
5137	Semet-Solvay Co., Milwaukee Coke & Gas Co., Milwaukee, Wis.	1.8	1.5	1.4	1.2
5121	Semet-Solvay Co., Pennsylvania Steel Co., Lebanon, Pa.	0.6	0.5	1.6	1.3
5125	By-Products Coke Corporation, South Chicago, Ill.	([7])	([7])	0.4	0.3
5128	Semet-Solvay Co., Detroit, Mich.	6.9	5.9	[9]2.8	2.3
5200	Semet-Solvay Co., Empire Coke Co., Geneva, N. Y.	4.0	3.4	2.6	2.1
5189	Semet-Solvay Co., Dunbar Furnace Co., Dunbar, Pa.	2.0	1.7	1.7	1.4
5160	Semet-Solvay Co., Central Iron & Coal Co., Tuscaloosa, Ala.	3.2	2.8	2.4	1.9
5074	Philadelphia Suburban Gas & Electric Co., Chester, Pa.	2.3	2.0	2.3	1.3
5081	Semet-Solvay Co., Ensley, Ala.	3.3	2.8	[8]1.4	1.0
5095	The New England Gas & Coke Co., Everett, Mass.	2.2	2.0	2.9	2.3
5083	Lackawanna Steel Co., Lackawanna Iron & Steel Co., Lebanon, Pa.	5.4	4.4	[9]1.4	1.4
5159	Dominion Tar & Chemical Co., Sydney, Nova Scotia	3.2	2.8	1.9	1.5
5107	Hamilton Otto Coke Co., Hamilton, O.	3.4	3.0	3.1	2.5
5086	Carnegie Steel Co., South Sharon, Pa.	1.0	1.0	[9]1.6	1.2
5078	Maryland Steel Co., Sparrows Point, Md.				
5087	Citizens' Gas Co., Indianapolis, Ind.	1.6	1.3	1.3	0.9
5109	Pittsburg Gas & Coke Co., The United Coke & Gas Co., Glassport, Pa.	1.2	1.1	1.1	0.9
5122	Zenith Furnace Co., Duluth, Minn.	1.1	1.0	1.1	0.9
5188	Illinois Steel Co., Joliet, Ill.	3.6	3.0	1.7	1.3
5404	Illinois Steel Co., Indiana Steel Co., Gary, Ind.	1.9 3.5	1.6 3.0	[9]1.7 [9]1.3	1.2 1.0
5108	Camden Coke Co., Camden, N. J.	2.2	1.9	1.8	1.4
5127	Cambria Steel Co., Johnstown, Pa.	10.1	8.3	[9]3.1	2.3
5089	Lackawanna Steel Co., Buffalo, N. Y.	2.7	2.2	[10]0.5	0.3

REFERENCES TO TABLE 46

[1] Approximately.
[2] No information.
[3] Varies with coal. Coal with 28 per cent of volatile matter used.
[4] With H_2O.
[5] At present.
[6] Variable.
[7] Trace.
[8] Trace of solids.
[9] Distillate solid.
[10] Distillate one-fourth solid.
[11] Distillate nine-tenths solid.
[12] Distillate three-fourths solid.
[13] Distillate eight-ninths solid.
[14] Distillate one-half solid.

—*Continued*

Examination, office of public roads

Distillation results

Middle oils, 110°–170°C.		Heavy oils, 170°–270°C.		Heavy oils, 270°–315°C.		Pitch		Serial No.
Per cent by volume	Per cent by weight	Per cent by volume	Per cent by weight	Per cent by volume	Per cent by weight	Per cent by volume	Per cent by weight	
0.8	0.7	[12]13.1	11.5	[19] 8.2	7.3	[25]76.6	79.1	5126
[9]2.0	1.7	[9]14.0	12.3	[20] 7.9	6.9	[26]74.7	77.6	5123
0.7	0.6	14.9	13.2	[21]11.9	10.6	[27]69.5	73.1	5124
0.8	0.6	[13]21.1	18.9	[20] 5.5	4.9	[25]69.4	72.5	5137
0.8	0.6	[14]17.5	15.5	[19] 9.4	8.4	[25]70.1	73.7	5121
[12]1.1	0.9	[15]23.6	20.7	[9] 9.8	8.9	[27]65.1	68.9	5125
[9]0.4	0.3	[11]14.6	13.0	[8] 6.9	5.7	[26]68.4	72.0	5128
0.6	0.5	[10]17.6	15.5	[22]11.4	10.4	[27]63.8	67.7	5200
0.2	0.2	[16]20.0	17.8	[21] 6.5	5.7	[25]69.6	73.1	5189
0.3	0.3	18.6	16.3	[10] 7.5	6.8	[27]68.0	71.5	5160
1.2	0.8	22.8	19.5	[19]13.6	12.5	57.8	62.0	5074
0.2	0.2	[17]16.5	14.1	[14] 9.3	8.2	[27]69.3	73.2	5081
0.6	0.5	23.5	20.4	[17]15.6	14.4	[27]55.2	59.7	5095
[9]0.1	0.1	[11]13.0	10.9	[21] 9.4	8.1	[25]70.7	74.6	5083
0.6	0.5	27.2	24.2	[19] 7.3	6.7	[27]59.8	63.5	5159
0.7	0.6	27.9	24.4	[19] 3.8	3.5	[27]61.1	64.9	5107
[9]0.6	0.4	[16]12.1	10.2	[19]11.0	9.7	[25]73.7	77.5	5086
0.6	0.4	[12]17.2	15.1	[21] 9.6	8.5	[28]69.7	73.2	5078
1.4	1.3	23.9	21.4	[10]11.6	10.4	[27]60.8	64.7	5087
0.5	0.4	[18]26.9	23.6	[14] 6.9	6.3	[27]63.5	67.6	5109
0.4	0.3	[11]18.1	15.9	[19]12.5	11.1	[27]63.7	67.8	5122
[9]0.2	0.2	[9]20.0	18.0	[11]13.4	12.0	[26]62.8	66.3	5188
[9]0.4	0.3	[9]20.6	18.5	[9] 7.1	6.5	[26]67.1	70.2	5404
0.6	0.5	[14]20.5	18.2	[23] 8.5	7.5	[25]66.4	70.1	5108
[9]0.3	0.2	[9] 7.1	6.1	[12] 7.4	6.9	[26]72.0	74.8	5127
[9]2.2	1.7	[9]11.7	9.9	[24]11.8	10.2	[27]71.1	75.0	5089

REFERENCES TO TABLE 46

[16] Distillate two-thirds solid.
[16] Distillate four-fifths solid.
[17] Distillate seven-eighths solid.
[18] Distillate one-ninth solid.
[19] Distillate one-third solid.
[20] Distillate one-sixth solid.
[21] Distillate one-fifth solid.
[22] Distillate two-fifths solid.
[23] Distillate one-seventh solid.
[24] Distillate three-fifths solid.
[25] Pitch soft and sticky.
[26] Pitch very soft and sticky.
[27] Pitch hard and brittle.
[28] Pitch plastic.

material and the method of manufacture; the operation, known as "cracking," which is used to increase the yield of the inflammable oils, produces an excess of free carbon.

The paraffin petroleum residuums are soft and greasy and are not suitable for road work; they contain a large amount of the paraffin hydrocarbons and paraffin scale (crude paraffin).

The California petroleum residuums resemble asphalt, and if carefully distilled with cracking should contain little or no free carbon. They are suited to road work.

The Texas, or semi-asphaltic petroleums contain some paraffin hydrocarbons and about 1 per cent of paraffin scale. Residuums from these oils, if containing a relatively small amount of paraffin, can be successfully used.

The required properties of residuum bituminous binders used on the New York State roads in 1922 are given, page 438.

The preceeding tables give a general idea of the relative characteristics of the crude petroleums and petroleum residuums.

Tests of Bitumens and Their Significance.—Bitumens for use as the cementing material in road construction may, according to their source and characteristics, be divided into the two general classes of asphalt and tars.

The asphalts suitable for use as the cementing agent in road construction are produced either by reducing asphaltic base petroleum to a suitable consistency by the distillation process or by softening the so-called solid asphalts to a suitable consistency by the addition of flux produced by the partial distillation of petroleum.

The different grades, relative to consistency, of road oils are usually produced by the partial reduction of asphaltic base petroleum.

By the destructive distillation of bituminous coals or the "cracking" of petroleum oils during the carburetting process in the manufacture of water gas, crude tars are produced. These crude tars are refined or reduced by distillation to a suitable consistency for use in road construction.

Bitumens are used in road construction for the purpose of waterproofing the surface and adding to the mechanical bond of the mineral aggregate by cementing together the finer particles of mineral matter, thus preventing their displacement under the action of traffic and retaining them in the road surface where they fill the interstices between the larger stone and bind them together.

The desirable characteristics of bituminous material for road building purposes, are first, Adhesiveness, second, Non-susceptibility to changes in temperature, and third, Stability or "life." The chief object of bituminous material specifications is to make imperative these desirable qualities of the material.

In connection with testing bituminous materials the thought should be kept in mind that the laboratory results obtained in the different tests are largely for comparative purposes. By this means new or but little used materials may be compared with materials which have proven satisfactory under service tests. Also laboratory results furnish an accurate means of specifying the exact characteristics of the material desired for any given purpose.

Adhesiveness.—The adhesiveness of the material is provided for in specifications by suitable requirements of ductility and toughness.

The ductility and toughness tests are made for the purpose of determining the adhesive and binding qualities of the material under different conditions of temperature. The ductility test is made by determining the distance a briquette of the material, having a standard cross-section (1 sq. cm.) will draw out before breaking. Since temperature affects the results, a standard temperature of 77°F., has been adopted generally for making this test. Experience teaches that the greater the distance that a briquette of the material will stretch out before breaking the more sticky and adhesive the material. This test may be performed in a rough manner by pulling out a small roll of the material between the fingers. Material which will not pull out to a long thread before breaking is usually spoken of as "short." Such materials are not adhesive or sticky and it is extremely difficult to bind a road with them, even under the most favorable circumstances.

As stated, the ductility test is usually made at a temperature of 77°F. and thus measures the adhesiveness of the material at a rather high temperature. To obtain an indication of the character of the material at a low temperature the Toughness test is made at a temperature of 32°F. This test is performed by dropping a weight of 2 kg. on a cylinder of

the material $1\frac{3}{4}$ in. in diameter by $1\frac{3}{4}$ in. in height. The first height of the drop is usually from a distance of 5 cm. and is gradually increased until rupture of the cylinder occurs. A rough field test for toughness may be performed by noting whether a piece of the material will fracture under a sharp blow. If the temperature of the material is about 32°F., the results will be more indicative of the character of the material.

Bitumens which are brittle or which give a low toughness result, lose their binding value in cold weather and roads constructed by their use are apt to ravel and break up under traffic.

Bitumens which give good ductility and toughness results under the methods outlined, will give satisfactory results as the cementing medium when used in road construction provided the other construction details have been properly followed out.

In connection with the stickiness and adhesiveness of bitumens the fact should always be kept in mind that their purpose in road construction as acementing medium, is most effective when used with a hard, clean, dry mineral aggregate. As the departure from these qualities of the mineral aggregate increase so also are increased the difficulties of getting a satisfactory road surface firmly bound together.

Susceptibility to Changes in Temperature.—The susceptibility to changes in temperature is shown by the relative hardness as indicated by the penetration tests at different temperatures, as 32°F., 77°F. and 115°F.

The consistency of asphalts is referred to as the "penetration." The penetration test is made by measuring the distance in hundredths of a centimeter that a standard needle under a stated load, applied for a stated time, will penetrate into it vertically. These variable factors are usually as follows:

Needle—R. J. Roberts' Parabola "Sharps" No. 2.
at 32°F. 200 g. weight, 1 min.
at 77°F. 100 g. weight, 5 sec.
at 115°F. 50 g. weight, 5 sec.

The material which is the most susceptible to changes in temperature will show the greatest variation in penetration under varying conditions of temperature. Roads constructed by the use of materials which are extremely susceptible to changes in temperature become soft in warm weather, mark easily, have a tendency to rut and become wavy In cold weather this material becomes very hard and slippery and is apt to be brittle and become chipped from the road surface.

In addition to the general qualities of bitumens which are shown by penetration tests, this test is used in specifications to define within narrow limits the consistency of the material. The consistency limits placed in specifications are governed by the climate and the type of construction to be followed, also the general size of the mineral aggregate to be used. When the penetration method of construction is followed it is necessary to use a relatively soft asphalt in order that it may be incorporated in the road surface. In the mixing types of construction a harder asphalt may be incorporated with the mineral aggregate. The use of a hard asphalt together with a graded mineral aggregate gives a dense wearing surface that does not readily become wavy under traffic.

The information obtained by the penetration test is not readily checked in the field without the aid of laboratory apparatus, but as a general rule bitumens which are suitable for binders are plastic when "worked" in the hands.

Stability.—When the term "Stability" or "Life" is used in reference to bitumens it refers to the quality of the material by which it retains its characteristics, over a long period of time. The laboratory tests which indicate this property are the evaporation test, the rotio of the penetration after evaporation to the original penetration, and the flash point.

The heating or evaporation test, is made by placing 50 g. of the material in a flat-bottomed dish $2\frac{3}{16}$ in. in diameter by $1\frac{3}{8}$ in. in depth. This is placed in an oven maintained at a specified temperature, usually 325°F. for a period of 5 hours.

This test may be considered as an accelerated test on the material. In a binder, the percentage lost by weight together with the resulting hardening as shown by the relative penetration, *i.e.*, the ratio of the original penetration to the penetration after evaporation, are indicative of the "life" of the material. The less the evaporation loss and the less the hardening as shown by the relative penetration the greater will be the "life" of the material.

In an oil used for surface application the evaporation test shows the presence and quantity of light oils. This is indicative of the time required for the oil to "set up" after application to the road surface; the evaporation from the large surface area of the oil as applied to the road being roughly comparable with evaporation from the smallest surface area of the oil exposed at the higher temperature at which the test is made.

The open flash test is made by heating at the rate of about 10°F. per minute, a small quantity of the material, approximately 40 g. in a dish of approximately the same size as the dish used for the penetration tests, $2\frac{3}{16}$ in. in diameter by 1 $\frac{3}{8}$ in. in depth. A small flame from a capillary tube is passed over the surface of the oil at each increase of 5° in temperature.

A slight "puff" or explosion indicates the flash point has been reached. The presence of light oils or distillates is indicated by a low flash point. The flash point together with the evaporation results gives an indication as to the methods and materials used in the manufacture of the bitumen which is being tested.

Unless "cut-back" materials are being tested, in which an exceedingly light distillate as naphtha or benzole has been used as the "cut-back" agent, considerable "smoke" will be given off from the sample before the flash point is reached. This feature should be kept in mind when material is being heated for application in the field. Material should never be heated in the field to a point when it smokes profusely, for at such a temperature the material is being "burned" or hardened to such an extent that it loses its adhesiveness and becomes brittle when cold, thus failing to become a binding or cementing agent which binds the mineral aggregate of the road together.

The same "burning" effect on the material is produced by keeping it at a temperature below the "smoking point" for a long period (several hours) as would be produced at a higher temperature for a shorter period of time. This important feature should always be kept in mind when heating material for application in the field.

Such tests as those for water, specific gravity, purity, paraffine, etc. are usually placed in specifications in addition to the tests which govern adhesiveness, non-susceptibility and stability for the purpose of identification of materials used, methods of manufacture, degree of refinement and care used in refining.

The presence of water in bituminous materials causes frothing when heated to a temperature of about 212°F. In addition to the difficulty experienced in heating material containing water, due to the frothing, an even application or distribution to the road of such material is extremely difficult due to the presence of the froth which is apt to be applied rather than the liquid bitumen.

Tests for specific gravity, purity, paraffine, etc. require laboratory apparatus to get results which indicate qualities of the material. The information obtained by these tests cannot be obtained by field tests.

If we assume that a suitable bitumen has been specified and obtained for construction work in which a bitumen is to serve as the cementing material, the results obtained, relative to the bitumen, will depend upon:

1. Not over-heating (by high temperature or long time) the bitumen.
2. The use of hard, clean, dry stone.
3. Grading of the mineral aggregate to reduce the voids and obtain greater density.
4. Thorough and uniform incorporation of the bitumen with the mineral aggregate.
5. Maximum consolidation, by rolling when laid.

When bituminous materials which may be applied cold are to be applied to a road surface, that surface should first be put in good condition. Surface application treatment is for the purpose of preserving a road which is in good condition and not repairing an uneven road. We do not repair a house by painting it; rather we repair the house and then paint it, in order that it may remain in good condition. An attempt to build up a road-wearing surface by the use of bitumens which may be applied cold usually results in a surface which is easily marked, ruts and pushes into waves.

The following detailed description of Recent Test Methods for asphalts is quoted from Brochure 8, Asphalt Association:

METHODS OF TESTING

The following methods of testing are those to which reference is made in the specifications. Some of the descriptions have been condensed, but not changed in any essential particular.

SPECIFIC GRAVITY

[*Bulletin* 314, U. S. Dept. Agriculture p. 5.]

Pycnometer Method.—The pycnometer, shown in Fig. 1, consists of a fairly heavy, straight-walled glass tube, 70 mm. long and 22 mm. in diameter, carefully ground to receive an accurately fitting solid glass stopper with a hole of 1.6 mm. bore in place of the usual capillary opening. The lower part of this stopper is made concave in order to allow all air bubbles to escape through the bore. The depth of the cup-shaped depression is 4.8 millimeters at the center. The stoppered tube has a capacity of about 24 cubic centimeters and when empty weighs about 28 g.

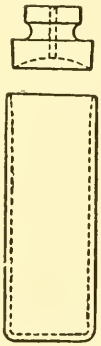


FIG. 1.—Pycnometer (Hubbard type).

The clean, dry pycnometer is first weighed empty and this weight is called "*a*." It is then filled in the usual manner with freshly distilled water at 25°C., and the weight is again taken and called "*b*." A small amount of the bitumen should be placed in a spoon and brought to a fluid condition by the gentle application of heat, with care that no loss by evaporation occurs. When sufficiently fluid, enough is poured into the dry pycnometer, which may also be warmed, to fill it about half full, without allowing the material to touch the sides of the tube above the desired level. The tube and contents are then allowed to cool to room temperature, after which the tube is carefully weighed with the stopper. This weight is called "*c*." Distilled water, at 25°C., is then poured in until the pycnometer is full. After this the stopper is inserted, and the whole cooled to 25°C. by a 30-min. immersion in a beaker of distilled water maintained at this temperature. All surplus moisture is then removed with a soft cloth, and the pycnometer and contents are weighed. This weight is called "*d*." From the weights obtained the specific gravity of the bitumen may be readily calculated by the following formula:

$$\text{Specific gravity } 25°\text{C.}/25°\text{C.} = \frac{c - a}{(b - a) - (d - c)}$$

The specific gravity of fluid bitumen may be determined in the ordinary manner with this pycnometer by completely filling it with the material and dividing the weight of the bitumen thus obtained by that of the same volume of water.

FLASH POINT

[*Bulletin* 314, U. S. Dept. Agriculture, p. 17.]

Open-cup Method.—The open-cup oil tester, shown in Fig. 2, consists of a brass oil cup *a* of about 100 cubic centimeter capacity, and an outer vessel *b* which serves as an air jacket; a suitable thermometer *c* is suspended from the wire support *d* directly over the center of the cup so that its bulb is entirely covered with asphalt but does not touch the bottom of the cup. The testing flame is obtained from a jet of gas passed through a piece of glass tubing, and should be about 5 mm. in length.

The test is made by first filling the oil cup with the material under examination to within about 5 mm. of the top. The Bunsen flame is then applied in such a manner that the temperature of the material in the cup is raised at the rate of 5°C. per minute, From time to time the testing flame is brought almost in contact with the surface of the asphalt. A distinct flicker or flash over the entire surface of the asphalt shows that the flash point is reached and the temperature at this point is taken.

PENETRATION

[A. S. T. M. Standard Test D5–16.]

I. Definition. (1) *Penetration.*—Penetration is defined as the consistency of a bituminous material expressed as the distance that a standard needle vertically penetrates a sample of the material under known conditions of loading, time and temperature. When the conditions of test are not specifically mentioned, the load, time and temperature are understood to be 100 g., 5 sec., 25°C. (77°F.), respectively, and the units of penetration to indicate hundredths of a centimeter.

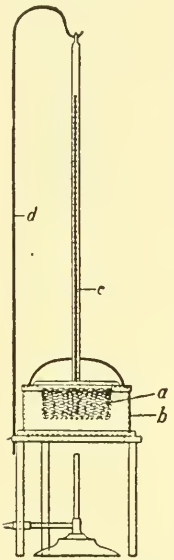


FIG. 2.—Open-cup oil tester.

II. Apparatus. (2) *Container.*—The container for holding the material to be tested shall be a flat-bottom, cylindrical dish, 55 mm. (2 3/16 in.) in diameter and 35 mm. (1 3/8 in.) deep.[1]

3. *Needle.*—The needle[2] for this test shall be of cylindrical steel rod 50.8 mm. (2 in.) long and having a diameter of 1.016 mm. (0.04 in.) and turned on one end to a sharp point having a taper of 6.35 mm. (1/4 in.).[3]

4. *Water Bath.*—The water bath shall be maintained at a temperature not varying more than 0.1°C. from 25°C. (77°F.). The volume of water shall not be less than 10 l. and the sample shall be immersed to a depth of not less than 10 cm. (4 in.) and shall be supported on a perforated shelf not less than 5 cm. (2 in.) from the bottom of the bath.

5. *Apparatus for Penetration.*—Any apparatus which will allow the needle to penetrate without appreciable friction, and which is accurately calibrated to yield results in accordance with the definition of penetration, will be acceptable.

6. *Transfer Dish for Container.*—The transfer dish for container shall be a small dish or tray of such capacity as will insure complete immersion of the container during the test. It shall be provided with some means which will insure a firm bearing and prevent rocking the container.

III. Preparation of Sample. (7) *Preparation of Sample.*—The sample shall be completely melted at the lowest possible temperature and stirred thoroughly until it is homogeneous and free from air bubbles. It shall then be poured into the sample container to a depth of not less than 15 mm. (5/8 in.). The sample shall be protected from dust and allowed to cool in an atmosphere not lower than 18°C. (65°F.) for 1 hour. It shall then be placed in the water bath along with the transfer dish and allowed to remain 1 hour.

IV. Testing. (8) *Testing.*—(*a*) In making the test the sample shall be placed in the transfer dish filled with water from the water bath of sufficient depth to completely cover the container. The transfer dish containing the sample shall then be placed upon the stand of the penetration machine. The needle, loaded with specified weight, shall be adjusted to make contact with the surface of the sample. This may be accomplished by making contact of the actual needle point with its image reflected by the surface of the sample from a properly placed source of light. Either the reading of the dial shall then be noted or the needle brought to zero. The needle is then released for the specified period of time, after which the penetration machine is adjusted to measure the distance penetrated.

At least three tests shall be made at points on the surface of the sample not less than 1 cm. (3/8 in.) from the side of the container and not less than 1 cm. (3/8 in.) apart. After each test the sample and transfer dish shall be returned to the water bath and the needle shall be carefully wiped toward its point with a clean, dry cloth to remove all adhering bitumen. The reported penetration shall be the average of at least three tests whose values shall not differ more than four points between maximum and minimum.

[1] This requirement is fulfilled by the American Can Co 's gill style ointment box, deep pattern, 3-ounce capacity.

[2] Journal of Agriculture Research, Vol. V, No. 24, pp. 1125–1126.

[3] Asphalt Association Note.—A No. 2 Roberts sewing needle which has been carefully checked with a standard needle may be used.

(*b*) When desirable to vary the temperature, time and weight and, in order to provide for a uniform method of reporting results when variations are made, the samples shall be melted and cooled in air as above directed. They shall then be immersed in water or brine, as the case may require, for 1 hour at the temperature desired. The following combinations are suggested:

At 0°C. (32°F.) 200 gm. weight, 60 sec.

At 46.1°C. (115°F.) 50 gm., weight, 5 sec.

DUCTILITY

[*Trans.* A. S. C. E., vol. LXXXII, 1918, p. 1460.]

"A briquette of the material to be tested shall be formed by pouring the molten material into a briquette mold. The dimensions of the briquette shall be: 1 cm. (0.394 in.) in thickness throughout its entire length; distance between the clips or end pieces 3 cm. (1.181 in.); width of asphalt cement section at mouth of clips, 1 cm. (0.394 in.). The center pieces are removable, the briquette mold being held together during molding with a clamp or wire.

"The molding of the briquette shall be done as follows: The two center sections shall be well amalgamated to prevent the asphalt cement from adhering to them, and the briquette mold shall then be placed on a freshly amalgamated brass plate. The asphalt cement to be tested, while in a molten state, shall be poured into the mold, a slight excess being added to allow for shrinkage on cooling. When the asphalt cement in the mold is nearly cool, the briquette shall be cut off level, with a warm knife or spatula. When it is thoroughly cooled to the temperature at which it is desired to make the test, the clamp and the two side pieces are removed, leaving the briquette of asphalt cement held at each end by the ends of the mold, which now play the part of clips. The briquette shall be kept in water for 30 min. at 4°C. (39°F.) or 25°C. (77°F.) before testing, dependent on the temperature at which the ductility is desired. The briquette and the clips attached shall then be placed in a ductility test machine' filled with water at one of the above temperatures to a sufficient height to cover the briquette not less than 50 mm. (1.969 in.). This machine consists of a rectangular water-tight box, having a movable block working on a worm-gear from left to right. The left clip is held rigid by placing its ring on a short metal peg provided for this purpose; the right clip is placed over a similar rigid peg on the movable block. The movable block is provided with a pointer which moves along a centimeter scale. Before starting the test, the centimeter scale is adjusted to the pointer at zero. Power is then applied by the worm-gear pulling from left to right at the uniform rate of 5 cm. (1.969 in.) per minute. The distance, in centimeters, registered by the pointer on the scale at the time of rupture of the thread of asphalt cement shall be taken as the ductility of the asphalt cement."

VOLATILIZATION TEST

[*Bulletin* 314, U. S. Dept. Agriculture, p. 19.]

The oven shown in Fig. 3, known as the New York testing laboratory oven, is used by the Bureau of Public Roads, although any other form may be used that will give a uniform temperature throughout all parts where samples are placed. The bulb of one of the thermometers is immersed in a sample of some fluid, nonvolatile bitumen, while the other is kept in air at the same level. The first thermometer serves to show the temperature of the samples during the test, while the latter gives prompt warning of any sudden changes in temperature due to irregularities in the gas pressure, etc.

Before making the test the interior of the oven should show a temperature of 163°C. as registered by the thermometer in air. A round tin box 5½ cm. in diameter and 3½ cm. deep is accurately weighed after carefully wiping with a towel to remove any grease or dirt. About 50 g. of the material to be tested is then placed in the box. The material may then be weighed on a rough balance, if one is at hand, after which the accurate weight, which should not vary more than 0.2 g. from the specified amount is obtained. It may be necessary to warm some of the material in order to handle it conveniently, after which it must be allowed to cool before determining the accurate weight.

The sample should now be placed in the oven, where it is allowed to remain for a period of 5 hours, during which time the temperature as shown by the thermometer in bitumen should not vary at any time more than 2°C. from 163°C. The sample is then removed from the oven, allowed to cool, and reweighed. From the difference between this weight and the total weight before heating, the percentage of loss on the amount of material taken is calculated.

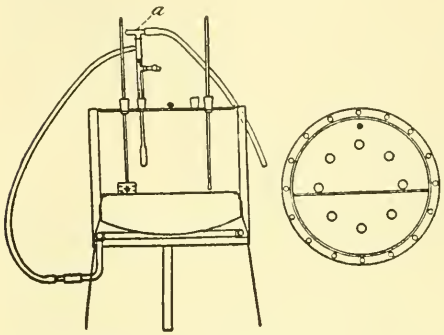


FIG. 3.—New York Testing Laboratory oven.

Highly volatile and nonvolatile materials should not be subjected to this test at the same time in the same oven, owing to a tendency on the part of the latter to absorb some of the volatile products of the former.

Some relative idea of the amount of hardening which has taken place may be obtained from the results of a float or penetration test made on the residue, as compared with the results of the same tests on the original sample. Before any tests are made on the residue, it should be melted and thoroughly stirred while cooling.

TOTAL BITUMEN

[*Bulletin* 314, U. S. Dept. Agriculture, p. 25.]

Gooch Crucible Method.—This test consists in dissolving the bitumen in carbon disulphide and recovering any insoluble matter by filtering the solution through an asbestos felt. The form of Gooch crucible best adapted for the determination is 4.4 cm. wide at the top, tapering to 3.6 cm. at the bottom, and is 2.5 cm. deep.

For preparing the felt the necessary apparatus is arranged as shown in Fig. 4, in which *a* is the filtering flask, *b* a rubber stopper, *c* the filter tube, and *d* a section of rubber tubing which tightly clasps the Gooch crucible *c*. The asbestos is cut with scissors into pieces not exceeding 1 cm. in length, after which it is shaken up with just sufficient water to pour easily. The crucible is filled with the suspended asbestos, which is allowed to settle for a few moments. A light suction is then applied to draw off all the water and leave a firm mat of asbestos in the crucible. More of the suspended material is added, and the operation is repeated until the felt is so dense that it scarcely transmits light when held so that the bottom of the crucible is between the eye and the source of light. The felt should then be washed several times with water and drawn firmly against the bottom of the crucible by an increased suction. The crucible is removed to a drying oven for a few minutes, after which it is ignited at red heat over a Bunsen burner, cooled in a desiccator, and weighed.

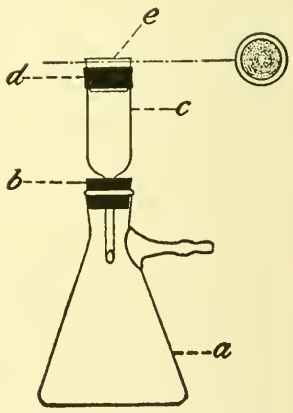


FIG. 4.—Apparatus for determining soluble bitumen.

From 1 to 2 g. of the bituminous material is now placed in the Erlenmeyer flask, which has been previously weighed, and the accurate weight of the sample is obtained. One hundred cubic centimeters of chemically pure carbon disulphide is poured into the flask in small portions, with continual agitation, until all lumps disappear and nothing adheres to the bottom. The flask is then corked and set aside for 15 min.

After being weighed the Gooch crucible containing the felt is set up over the dry pressure flask, as shown in the figure, and the solution of bitumen in carbon disulphide is decanted through the felt without suction by gradually tilting the flask, with care not to stir up any precipitate that may have settled out. At the first sign of any sediment coming

out, the decantation is stopped and the filter allowed to drain. A small amount of carbon disulphide is then washed down the sides of the flask, after which the precipitate is brought upon the felt and the flask scrubbed, if necessary, with a feather or "policeman," to remove all adhering material. The contents of the crucible are washed with carbon disulphide, until the washings run colorless. Suction is then applied until there is practically no odor of carbon disulphide in the crucible, after which the outside of the crucible is cleaned with a cloth moistened with a small amount of the solvent. The crucible and contents are dried in a hot-air oven at 100°C. for about 20 min., cooled in a desiccator, and weighed. If any appreciable amount of insoluble matter adheres to the flask, it should also be dried and weighed, and any increase over the original weight of the flask should be added to the weight of insoluble matter in the crucible. The total weight of insoluble material may include both organic and mineral matter. The former, if present, is burned off by ignition at a red heat until no incandescent particles remain, thus leaving the mineral matter or ash, which can be weighed on cooling. The difference between the total weight of material insoluble in carbon disulphide and the weight of substance taken equals the total bitumen, and the percentage weights are calculated and reported as total bitumen, and organic and inorganic matter insoluble, on the basis of the weight of material taken for analysis.

This method is quite satisfactory for most asphalts, but where certain lake asphalts are present it will be found practically impossible to retain all of the finely divided mineral matter on an asbestos felt. It is, therefore, generally more accurate to obtain the result for total mineral matter by direct ignition of a 1-g. sample in a platinum crucible. The total bitumen is then determined by deducting from 100 per cent the sum of the percentages of total mineral matter and organic matter insoluble. If the presence of a carbonate mineral is suspected, the percentage of mineral matter may be most accurately obtained by treating the ash from a fixed carbon determination with a few drops of ammonium carbonate solution, drying at 100°C., then heating for a few minutes at a dull red heat, cooling, and weighing again.

When difficulty in filtering is experienced—for instance, when Trinidad asphalt is present in any amount—a period of longer subsidence than 15 min. is necessary, and the following method proposed by the Committee on Standard Tests for Road Materials of the American Society for Testing Materials is recommended.[1]

From 2 to 15 g. (depending on the richness in bitumen of the substance) is weighed into a 150-c.c. Erlenmeyer flask, the tare of which has been previously ascertained, and treated with 100 c.c. of carbon disulphide. The flask is then loosely corked and shaken from time to time until practically all large particles of the material have been broken up, when it is set aside and not disturbed for 48 hours. The solution is then decanted off in a similar flask that has been previously weighed, as much of the solvent being poured off as possible without disturbing the residue. The first flask is again treated with fresh carbon disulphide and shaken as before, when it is put away with the second flask and not disturbed for 48 hours.

At the end of this time the contents of the two flasks are carefully decanted off upon a weighed Grooch crucible fitted with an asbestos filter, the contents of the second flask being passed through the filter first. The asbestos filter shall be made of ignited long-fiber amphibole, packed in the bottom of a Grooch crucible to the depth of not over one-eighth of an inch. After passing the contents of both flasks through the filter, the two residues are shaken with more fresh carbon disulphide and set aside for 24 hours without disturbing, or until it is seen that a good subsidation has taken place, when the solvent is again decanted off upon the filter. This washing is continued until the filtrate or washings are practically colorless.

The crucible, and both flasks are then dried at 125°C. and weighed. The filtrate containing the bitumen is evaporated, the bituminous residue burned, and the weight of the ash thus obtained added to that of the residue in the two flasks and the crucible. The sum of these weights deducted from the weight of substance taken gives the weight of bitumen extracted.

BITUMEN SOLUBLE IN CARBON TETRACHLORIDE

[*Bulletin* 314, U. S. Dept. Agriculture, p. 30.]

Gooch Crucible Method.—This determination is made in exactly the same manner as described under "Total Bitumen" using carbon tetrachloride as a solvent instead of carbon disulphide.

[1] *Proc. Am. Soc. Testing Materials*, 1909, vol. IX, p. 221.

The percentage of bitumen soluble is reported upon the basis of total bitumen taken as 100. Thus if the percentage soluble in carbon tetrachloride should be found to be 98.5 per cent and the percentage soluble in carbon disulphide 99.0 per cent the percentage of total bitumen soluble in carbon tetrachloride would be

$$\frac{98.5}{99.0} = 99.6 \text{ per cent}$$

MELTING POINT

[A. S. T. M. Standard Method D 36–19.]

Ring and Ball Method.—(1) The softening of bituminous materials generally takes place at no definite moment or temperature. As the temperature rises, they gradually and imperceptibly change from a brittle or exceedingly thick and slow-flowing material to a softer and less viscous liquid. For this reason the determination of the softening point must be made by a fixed, arbitrary and closely defined method if the results obtained are to be comparable.

I. Apparatus.—(2) The apparatus shall consist of the following:

Ring

(*a*) A brass ring 15.875 mm. (5/8 in.) inside diameter and 6.35 mm. (1/4 in.) deep; thickness of wall, 2.38 mm. (3/32 in.); permissible variation on inside diameter and thickness of ring, 0.25 mm. (0.01 in.). This ring shall be attached in a convenient manner to a No. 15 B. & S. gage brass wire (diameter 1.79 mm. = 0.0703 in.). See Fig. 5.

(*b*) A steel ball 9.53 mm. (3/8 in.) in diameter weighing between 3.45 and 3.55 g.

Container

(*c*) A glass vessel, capable of being heated, not less than 9 cm. (3.54 in.) in diameter by 13 cm. (5.12 in.) deep. (A 600-c.c. beaker. Griffin low form, meets this requirement.)

Thermometer

(*d*) A thermometer which shall conform to the following specifications:

Total length, 370–400 mm. (14.57–15.75 in.).

Diameter, 6.5–7.5 mm. (0.256–0.295 in.).

Bulb length, not over 14 mm. (not over 0.55 in.).

Bulb diameter, 4.5–5.5 mm. (0.177–0.217 in.).

The scale shall be engraved upon the stem of the thermometer, shall be clear cut and distinct, and shall run from 0 to 80°C. (32 to 176°F.) in 1/2°C. divisions. It shall commence not less than 7.5 cm. (2.95 in.) above the bottom of the bulb. The thermometer shall be furnished with an expansion chamber at the top and have a ring for attaching tags. It shall be made of a suitable quality of glass and be so annealed as not to change its readings under conditions of use. It shall be correct to 0.25°C. (0.45°F.) as determined by comparison at full immersion with a similar thermometer calibrated at full immersion by the United States Bureau of Standards.

Preparation of Sample

II. Preparation of Sample.—(3) The sample shall be melted and stirred thoroughly, avoiding incorporating air bubbles in the mass, and then poured into the ring so as to leave an excess on cooling. The ring, while being filled, should rest on a brass plate which has been amalgamated to prevent the bituminous material from adhering to it. After cooling, the excess material should be cut off cleanly with a slightly heated knife.

III. Testing.—(*a*) Bituminous Materials having Softening Points 90°C. (194°F.) or below.

Assembling

4. Assemble the apparatus as shown in Fig. 5. Fill the glass vessel to a depth of substantially 8.25 cm. (3.25 in.) with freshly boiled, distilled water at 5°C. (41°F.). Place the ball in the center of the upper surface of the bitumen in the ring and suspend it in the water so that the lower surface of the filled ring is exactly 2.54 cm. (1 in.) above the bottom of the glass vessel and its upper surface is 5.08 cm. (2 in.) below the surface of the water.

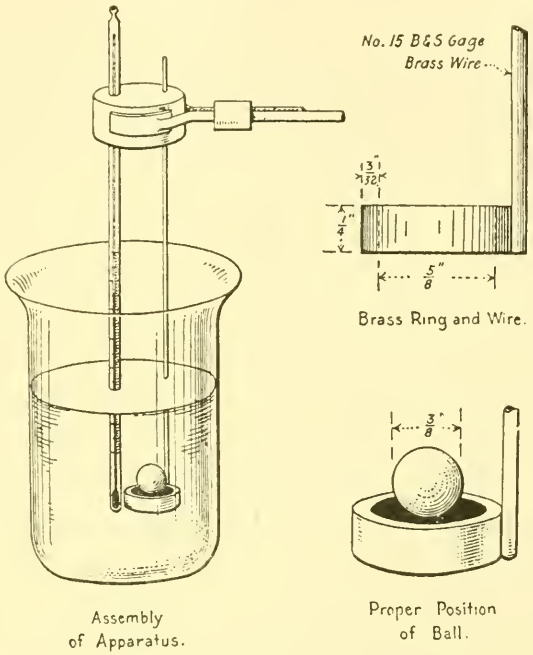


Fig. 5.—Ring and ball apparatus.

Allow it to remain in the water for 15 min. before applying heat. Suspend the thermometer so that the bottom of the bulb is level with the bottom of the ring and within 0.635 cm (1/4 in.), but not touching, the ring.

Heating

5. Apply the heat in such a manner that the temperature of the water is raised 5°C. (9°F.) each minute.

Softening Point

6. The temperature recorded by the thermometer at the instant the bituminous material touches the bottom of the glass vessel shall be reported as the softening point.

Permissible Variation in Rise of Temperature

7. The rate of rise of temperature shall be uniform and shall not be averaged over the period of the test. The maximum permissible variation for any minute period after the first three shall be ± 0.5°C. (0.9°F.). All tests in which the rate of rise in temperature exceeds these limits shall be rejected.

(*b*) Bituminous Materials having Softening Points above 99°C. (194°F.).

MODIFICATION FOR HARD MATERIALS

8. Use the same method as given under (*a*) except that glycerin shall be used instead of water.

ACCURACY

IV. Accuracy.—(9) The limit of accuracy of the test is ± 0.5°C. (0.9°F.).

PRECAUTIONS

V. Precautions.—(10) The use of freshly boiled, distilled water is essential, as otherwise air bubbles may form on the specimen and affect the accuracy of the results. Rigid adherence to the prescribed rate of heating is absolutely essential to secure accuracy of results.

A sheet of paper placed on the bottom of the glass vessel and conveniently weighted will prevent the bituminous material from sticking to the glass vessel, thereby saving considerable time and trouble in cleaning.

Cement.—There are five different classes of cement, Portland, Natural, Pozzolan, Iron Ore, and Magnesia cements. Of these the Portland is usually specified.

Portland cement is the term applied to the finely pulverized produce resulting from the calcination to incipient fusion of an intimate mixture of properly proportioned argillaceous and calcareous materials, and to which no addition greater than 3 per cent has been made subsequent to calcination. (Am. Soc. for Testing Materials, 1915—page 353.)

Natural cement is the term applied to the finely pulverized product resulting from the calcination of an argillaceous limestone at a temperature only sufficient to drive off the carbonic acid gas. (Am. Soc. for Testing Materials, 1915—p. 352.)

Portland cements are usually heavier, stronger, slower setting, and more uniform than the natural cements and are generally used for road structures, such as culverts, retaining walls, etc. Portland cement is practically the only cement used to any extent in the United States at the present time. The few manufacturers of natural cement who were retaining a hold on the market some few years back when the production of Portland cement was expensive, are finding it difficult to compete with this latter product at its present price and quality.

The following is the standard specification for portland cement as adopted by the American Society of Civil Engineers and the American Society for Testing Materials:

First: Specific Gravity.—The specific gravity of cement shall not be less than 3.10. Should the test of cement as received fall below this requirement, a second test may be made upon a sample ignited at a low red heat. The loss in weight of the ignited cement shall not exceed 4 per cent.

Second: Fineness.—It shall leave by weight a residue of not more than 8 per cent on the number 100, and not more than 25 per cent on the number 200 sieve.

Third: Time of Setting.—It shall not develop initial set in less than 30 min.; and must develop hard set in not less than 1 hour, nor more than 10 hours.

Fourth: Tensile Strength.—The minimum requirements for tensile strength for briquettes 1 sq. in. in cross-section shall be as follows and the cement shall show no retrogression in strength within the periods specified:

Age	Strength, pounds
Neat Cement	
24 hours in moist air	175
7 days (1 day in moist air, 6 days in water)	500
28 days (1 day in moist air, 27 days in water)	600
One Part Cement—Three Parts Standard Ottawa Sand	
7 days (1 day in moist air, 6 days in water)	200
28 days (1 day in moist air, 27 days in water)	275

Fifth: Constancy of Volume.—Pats of neat cement about 3 in. in diameter, ½ in. thick at the center, and tapering to a thin edge, shall be kept in moist air for a period of 24 hours.

(*a*) A pat is then kept in air at normal temperature and observed at intervals for at least 28 days.

(*b*) Another pat is kept in water maintained as near 70°F. as practicable, and observed at intervals for at least 28 days.

(*c*) A third pat is exposed in any convenient way in an atmosphere of steam, above boiling water, in a loosely closed vessel for 5 hours.

These pats, to satisfactorily pass the requirements, shall remain firm and hard, and show no signs of distortion, checking, cracking or disintegrating.

Sixth: Chemical Composition.—The cement shall not contain more than 1.75 per cent of anhydrous sulphuric acid (SO_3), nor more than 4 per cent of magnesia (MgO).

The equipment used in testing cement are standardized in detail and can be obtained in the "Year Book" published by the American Society for Testing Materials or Committee Report on "Uniform Tests of Cement" of the American Society of Civil Engineers 1922.

CONCRETE MATERIALS

Fine Aggregate.—Fine aggregate for use in cement or asphaltic concrete should consist of sand free from any deleterious matter. Any sand which shows a coating on the grains should not be used until satisfactorily cleansed by washing.

The following tests are made on sand to determine its suitability for use in different classes of concrete:

1. Gradation.
2. Percentage of voids.
3. Percentage of loam or slit.
4. Organic impurities.
5. Resistance to abrasion.
6. Compressive or tensile strength in cement mortar.

Mechanical Analysis of Aggregates

TABLE 1.—A. S. T. M. STANDARD SIEVES

Mesh designation	Unit of measure	Actual mesh	Opening	Wire diameter	Permissible variations	
					Mesh	Diameter
10[1]	cm.	3.9	0.200	0.056	0.04	0.005
	in.	9.9	0.079	0.022	0.1	0.002
20[1]	cm.	8.0	0.085	0.040	0.2	0.0015
	in.	20.3	0.0335	0.0157	0.5	0.0006
30	cm.	12.0	0.050	0.033	0.4	0.0012
	in.	30.5	0.0197	0.0130	1.0	0.0005
40[1]	cm.	16.0	0.036	0.026	0.6	0.0010
	in.	40.6	0.0142	0.0102	1.5	0.0004
50	cm.	20.0	0.029	0.021	0.8	0.0010
	in.	50.8	0.0114	0.0083	2.0	0.0004
80	cm.	31.0	0.017	0.015	1.0	0.0008
	in.	78.7	0.0067	0.0059	3.0	0.0003
100[1]	cm.	39.0	0.014	0.0116	1.0	0.0008
	in.	99.1	0.0055	0.0046	3.0	0.0003
200[1]	cm.	79.0	0.0074	0.0053	3.0	0.0005
	in.	200.7	0.0029	0.0021	8.0	0.0002

[1] It is recommended that for routine tests except for fine aggregate for hot mixed bituminous surfaces, the ¼-in. screen and these sieves be used.

STANDARD METHOD FOR MAKING A MECHANICAL ANALYSIS OF BROKEN STONE, BROKEN SLAG, OR GRAVEL PEBBLES

(A. S. T. M. Standard Method, Serial Designation: D18–16, slightly modified) Agg's Construction of Roads and Pavements.

The method shall consist of drying at not over 110°C. (230°F.) to a constant weight a sample weighing in pounds six times the diameter in inches of the largest holes required; passing the sample through such of the following size screens having circular openings as are required or called for by the specifications, screens to be used in the order named: 8.89 cm. (3½ in.), 7.62 cm. (3 in.), 6. 35 cm. (2½ in.), 5.08 cm. (2 in.), 3.81 cm. (1½ in.), 3.18 cm. (1¼ in.), 2.54 cm. (1 in.), 1.90 cm. (¾ in.), 1.27 cm. (½ in.), and 0.64 cm. (¼ in.); determining the percentage by weight retained on each screen; and recording the mechanical analysis in the following manner:

Passing 0.64 cm. (¼-in.) screen ..... per cent
Passing 1.27 cm. (½-in.) screen and retained on a 0.64 cm. (¼-in.) screen .. per cent
Passing 1.90 cm. (¾-in.) screen and retained on a 1.27 cm. (½-in.) screen) . per cent
Passing 2.54 cm. (1-in.) screen and retained on a 1.90 cm. (¾-in.) screen . per cent
..... per cent

100.00 per cent

STANDARD METHOD FOR MAKING A MECHANICAL ANALYSIS OF SAND OR OTHER FINE HIGHWAY MATERIAL

(A. S. T. M. Standard Method, Serial Designation: D7–18, slightly modified)

Adopted, 1919. Revised 1916, 1918

The method shall consist of drying at not over 110°C. (230°F.) to a constant weight of a sample weighing of from 100 gm. to 500 gm.; passing the sample through each of the mesh sieves (American Society for Testing Materials standard sieves) specified in Table 1;[1] determining the percentage by weight retained on each sieve, the sifting being continued on each sieve until less than 1 per cent of the weight retained on each sieve shall pass through the sieve during the last minute of sifting; and recording the mechanical analysis in the following manner:

Passing 200-mesh sieve	per cent
Passing 100-mesh sieve and retained on a 200-mesh sieve	per cent
Passing 80-mesh sieve and retained on a 100-mesh sieve	per cent
Passing 50-mesh sieve and retained on a 80-mesh sieve	per cent
	per cent
	100.00 per cent

MAKING A MECHANICAL ANALYSIS OF MIXTURES OF SAND OR OTHER FINE MATERIAL WITH BROKEN STONE, BROKEN SLAG OR GRAVEL PEBBLES

(A. S. T. M. Standard Method, Serial Designation: D19–16)

The method shall consist of drying at not over 110°C. (230°F.) to a constant weight a sample weighing in pounds six times the diameter in inches of the largest holes required; separating the sample by the use of a screen having circular openings 0.64 cm. (¼-in.) in diameter; examining the portion retained on the screen in accordance with the Standard Method for Making a Mechanical Analysis of Broken Stone or Broken Slag, except for Aggregates Used in Cement Concrete (Serial Designation: D18) of the American Society for Testing Materials; examining the portion passing this screen in accordance with the Standard Method for Making a Mechanical Analysis of Sand or Other Fine Highway Material, except for Fine Aggregates of Sand or Other Fine Highway Material, except for Fine Aggregates Used in Cement Concrete (Serial Designation D7) of the American Society for Testing Materials; and recording the mechanical analysis in the following manner:

Passing 200-mesh sieve	per cent
Passing 100-mesh sieve and retained on a 200-mesh sieve	per cent
Passing 80-mesh sieve and retained on a 100-mesh sieve	per cent
Passing 20-mesh and retained on 80-mesh.	
Passing 10-mesh sieve and retained on a 20-mesh sieve	per cent
Passing 0.64-cm. (¼-in.) screen and retained on a 10-mesh sieve	per cent
Passing 1.27-cm. (½-in.) screen and retained on a 0.64-cm. (¼-in.) screen	per cent
Passing 1.90-cm. (¾-in.) screen and retained on a 1.27-cm. (½-in.) screen	per cent
	per cent
	100.00 per cent

TEST FOR LOAM

Field Test.—It is convenient to have a graduated tube but any tall bottle will do. Fill bottle or tube about ⅓ or half full of sand to be tested. Add water till bottle or tube is nearly full. Stopper the top, turn into a horizontal position and shake vigorously. Change quickly to vertical position and leave for 24 hours without disturbing. The

[1] NOTE.—The order in which the sieves are to be used in the process of sifting is immaterial and shall be left optional, but in reporting results the order in which the sieves have been used shall be stated.

clay and loam will settle on top in a more or less clearly defined degree the amount of which can be easily measured. This method is sufficiently close for check field tests. The Standard Laboratory Test is described below.

Test for Amount of Clay and Silt in Sand or Fine Aggregate.—The sample as received shall be moistened and thoroughly mixed, then dried to constant weight at a temperature between 100°C. (212°F.) and 110°C. (230°F.).

Five hundred (500) grams representative of the dried sample shall be placed in a dried and accurately weighed pan or vessel having vertical sides and provided with a pouring lip. This pan shall be substantially 22.9 cm. (9 in.) in diameter by not less than 10.2 cm. (4 in.) deep. Pour sufficient water in the pan to cover the same (about 225 c.c.). Agitate vigorously for fifteen (15) seconds and then pour off the water into a tared evaporating dish, taking care not to pour off any sand. Repeat until the wash water is clear, using a glass rod to stir the material for the last few washings.

Thoroughly dry the pan and washed sand in an oven at between 100°C. (212°F.) and 110°C. (230°F.), weigh and determine net weight of sand.

Compute the per cent of clay and silt as follows:

$$\frac{\text{Original weight} - \text{weight after washing}}{\text{Original weight}} \times 100 = \text{per cent of clay and silt.}$$

For a check on the results, evaporate the wash water to dryness and weigh the residue.

$$\frac{\text{Weight of residue}}{\text{Original weight}} \times 100 = \text{per cent of clay and silt.}$$

Test for Amount of Clay and Silt in Gravel.—The sample as received shall be moistened and thoroughly mixed, then dried to constant weight at a temperature between 100°C. (212°F.) and 110°C. (230°F.).

A representative portion of the dry material, weighing not less than 50 times the weight of the largest stone in the sample, shall be selected from the sample, and placed in a dried and accurately weighed pan or vessel. The pan shall be 30.2 cm. (12 in.) in diameter by not less than 10.2 cm. (4 in.) deep, so nearly as may be obtained. Pour sufficient water in the pan to cover the gravel and agitate vigorously for fifteen (15) seconds, using a trowel or stirring rod. Allow to settle for fifteen (15) seconds, and then pour off the water into a tared evaporating dish, being careful not to pour off any sand. Repeat until the wash water is clear.

Dry the washed material to constant weight in an oven at between 100°C. (212°F.) and 110°C. (230°F.), weigh and determine net weight of gravel.

Compute the per cent of clay and silt as follows:

$$\frac{\text{Original weight} - \text{weight after washing}}{\text{Original weight}} \times 100 = \text{per cent of clay and silt.}$$

Colorimetric Test on Concrete Aggregate.—The test to be used is described in the "Proceedings of the American Society for Testing Materials, Philadelphia, Pennsylvania, Volume XIX, Par. 1, 1919. Appendix to Report of Committee C–9 on Concrete and Concrete Aggregates," and is as follows:

The test as usually made consists of shaking the sand thoroughly in a dilute solution of sodium hydroxide (NaOH) and observing the resultant color after the mixture has been allowed to stand for a few hours. Fill a 12-oz. graduated perscription bottle to the 4½ oz. mark with the sand to be tested. Add a 3 per cent solution of sodium hydroxide until the volume of the sand and solution, after shaking, amounts to 7 oz. Shake thoroughly and let stand for 24 hours. Observe the color of the clear liquid above the sand. A good idea of the quality of the sand can be formed earlier than 24 hours, although this period is believed to give best results.

If the solution resulting from this treatment is colorless, or has a light yellowish color, the sand may be considered satisfactory in so far as organic impurities are concerned. On the other hand, if a dark colored solution of a color deeper than that indicated is produced, the sand should not be used in high-grade concrete such as that required in roads and pavements, or in building construction.

Color Values.—While it is not practicable to give exact values for the reduction in strength corresponding to the different colors of solution, the tests made thus far show this relation to be about as follows.

Color number. Actual color prints can be obtained from Cement Assoc.	Reduction in compressive strength of 1.3 mortar at 7 and 28 days, per cent
Fig. 1	none
Fig. 2	10–20
Fig. 3	15–30
Fig. 4	25–50
Fig. 5	50–100

Washing dirty sands has the effect of greatly reducing the quantity of organic impurities. However, even after washing, sands should be examined in order to determine whether the organic impurities have been reduced to harmless proportions.

The following list includes sufficient apparatus for making five field tests at a time:

Five 12-oz. graduated prescription bottles; stock of 3 per cent solution of sodium hydroxide (dissolve 1 oz. of sodium hydroxide in enough water to make 32 oz.).

This test does not give satisfactory results when lignite is present in the sand. Lignite is a mineral coal of recent geological orgin. It is known commonly as "Brown" or "Sud" coal.

Water Tests.—Water must be clean and pure, free from organic impurities or oily content.

The usual tests are for

1. Organic impurities (see page 540).

2. Alkaline or acidre actions. This is determined by the common litmus paper test and if a strong acid or alkaline reaction is shown, the water should be rejected.

Proposed Abrasion Test for Fine Aggregate.—The following is suggested as a tentative method[1] for determining the resistance of the fine aggregate to abrasion. The fine aggregate is washed and dried at a temperature not exceeding 110°C. All material retained on the ¼-in. sieve, and all material passing a standard 50-mesh sieve is discarded. Five hundred (500) grams of the portion passing a ¼-in. screen and retained on a 50-mesh sieve are placed in a Deval abrasion cylinder with a charge of 250 g. of 9/16-in. commercial steel bearing balls (21 balls weigh practically 250 g.). The weight of the balls is to be within 1 per cent of the required 250 g. The charge in the Deval abrasion cylinder is rotated for 2,000 revolutions at the rate of 33 r.p.m. The sample of sand is removed and sieved over a 100-mesh sieve. The sample is preferably divided in three portions for sieving, the sieving being completed over a white sheet of paper, and is continued until practically no dust passes the sieve when shaken for 1 min. The portion retained on the 100-mesh sieve is weighed. Five hundred (500) grams, minus the weight of the samples retained on the 100-mesh after abrasion, is taken as the loss on abrasion. This weight divided by 5 gives the percentage of wear.

Slump Test for Consistency of Concrete.—For the determination of the consistency either in the field or in the laboratory the committee proposed the use of the 4 by 8 by 12 conical frustum.

In making the test, the thoroughly cleaned frustum should be placed on a level non-absorbent surface and filled with 3-in. layers of concrete. During filling, the mold should be held down by the operator placing his toes on the lip at the bottom of the mold. As each layer of material is introduced it should be puddled, with a ½-in. rod to distribute the material uniformly.

After the upper layer has been placed the top shall be struck off and the mold removed by slowly pulling it vertically upward. The height of the frustum shall be measured and the slump calculated from the difference of the height of the mold and the frustum.

In making the slump test in the laboratory or in the field it is recommended that the form be filled immediately after mixing and withdrawn 3 min. after mixing has been completed.

[1] AGG's "Construction of Roads and Pavements."

When central mixing plants are used, slump tests shall be made at the plant and at the end of the haul. At the plant the sample of concrete shall be taken after the entire batch has been discharged from the mixer. At the end of the haul the slump sample shall be taken from the batch after it has been dumped on the subgrade. The slump at the points of deposition shall be suitable for the particular type of finish employed. (See page 264.)

In order to secure suitable qualities, minimum requirements determined from the above tests should be definitely specified. For asphaltic concrete sand requirements see page 550.

The following specifications are now being used by Highway Departments in several of the States in regard to Cement Concrete Sand.

Sand for use in Portland cement concrete roads shall be of the following gradation: 100 per cent shall pass a ¼-in. screen, not more than 20 per cent shall pass a 50 sieve and not more than 6 per cent shall pass a 100 sieve. Sand may be rejected for this class if it contains more than 5 per cent of loam and silt. Mortar in the proportion of one part of cement to three parts of the sand, shall develop a compressive or tensile strength at least equal to the strength of a similar mortar of the same age, composed of the same cement and standard Ottawa sand.

Sand for use in foundations, culverts, retaining walls, etc. shall not contain more than 8 per cent of loam and silt. Mortar in the proportion of one part of cement to three parts of the sand, when tested shall develop a compressive or tensile strength of at least 80 per cent of the strength of a similar mortar of the same age, composed of the cement and standard Ottawa sand.

Screenings if substituted wholly or in part for the above sand, should meet the following requirements:

They shall be free from dust coating or other dirt. One-hundred per cent shall pass a ¼-in. screen and not more than 6 per cent shall pass a No. 100 sieve. Mortar in the proportions of three parts of the screenings or mixed screenings and sand, with 1 part of cement shall develop a strength equal to a sand for which it is to be substituted.

The best and safest way in the selection of a concrete sand is to have a fair representative sample from the deposit listed. After this is found to meet the requirements, it is necessary to have constant and careful field inspections and tests made as the deposit is worked.

The use of screenings is not advisable on any concrete work, except where a good grade of sand is not available. When used the product must be inspected constantly and tested as it is likely to vary to a considerable degree. Screenings from the softer limestones should not be used as the material is apt to "ball" in the mixer.

Sand used for grout in brick and stone block pavement must be fine enough to ensure it getting between the joints of the block, but an excessively fine sand should be avoided as it weakens the grout. Some states and many municipalities require the grout sand to pass a No.

20 sieve and not more than 30 per cent pass a No. 100 sieve. Such sand should not contain more than 5 per cent of loam and silt.

9. Coarse Aggregate.—Coarse aggregate for use in structural concrete should be of hard, durable stone gravel or blast furnace slag (see table of tests) free from coating of any kind. For use in concrete pavement, stone and gravel should be hard, tough and absolutely clean. For use in culverts, retaining walls, etc. stone, gravel or slag should be of sound, unweathered material, clean and free from coating. It should not contain more than 10 per cent of soft stone or shale. Gravel containing a large percentage of thin flat stone should not be used. Detail Test Methods follow.

For reinforced concrete the size of the stone is usually ½ to 1 in. in order to facilitate the compacting of the concrete between the reinforcing bars or mesh. For plain concrete a mixed size is used ranging from ½ to 3½ in.; a scientifically graded stone reduces the amount of mortar required, but the structures in road work are so small that it does not pay to attempt to reduce the voids in this manner and the size that is available is used, varying the proportions of mortar to get a dense product. For extensive concrete pavement of the first class graded sizes are feasible.

The use of slag in concrete is still a debatable matter but if proven to be reasonable will add materially to the source of concrete materials. All the indications and service tests seem to indicate that it is suitable for paving bases but that its use for concrete roads is to be avoided unless other suitable materials are prohibitive in cost.

Weight per Cubic Foot and Void Tests on Coarse Aggregate.—The weight per cubic foot of coarse aggregate shall be determined as follows:

A cylindrical measure of at least ¼-cu. ft. capacity with inside diameter approximately equal to inside height, or a box approximately cubical in shape and of not less than ½-cu. ft. capacity should be used.

Ordinarily, the determination should be made on aggregate in air-dry condition. When the aggregate contains an appreciable amount of moisture, the percentage of water by weight should be determined and recorded.

About ¼ of the total amount of aggregate necessary to fill the measure is first introduced in such manner as to avoid separation of sizes. This material is then shaken down by rocking the measure from side to side until no further settlement takes place. The process is repeated until the measure has been filled to overflowing, after which it is struck off level with the top with a straight edge and weighed.

The percentage of voids in the aggregate may be determined from the weight per cubic foot and specific gravity in the usual manner.

Method of Determining the Weight of Fine Aggregate per Cubic Foot.—For tests on fine aggregate use a cylindrical metal measure having inside diameter equal to inside depth. A measure of capacity of ⅛ to ½ cu. ft. is suggested, but a measure as small as 1/20 cu. ft. capacity may be used.

Ordinarily the weight per cubic foot should be determined on air-dry material. When the aggregate contains an appreciable amount of moisture the percentage of water by weight should be determined and recorded.

Fill the measure one-third full, puddle with 25 to 30 strokes from a ½-in. round steel bar 20 in. long, pointed at the lower end. Continue filling and puddling in like manner

until the measure is full, then strike off the top by a rolling motion with the bar. Determine the weight of the contents of the measure and calculate the weight in pounds per cubic foot.

Specific Gravity and Absorption Tests on Stone or Other Coarse Materials.—The apparent specific gravity is obtained by weighing the water displaced by a sample of the material weighing approximately 1,000 gm., broken into pieces about 1¼ in. in diameter. A special type of vessel is used. It consists of a galvanized iron cylinder closed at one end, and measuring 5 in. in diameter by 8 in. high. A brass spout ½ in. in diameter is soldered into the side of the cylinder 6 in. from the bottom. The spout is inclined at an angle of 2 with the horizontal and is 2½ in. long. A notch is filed across its lower end, as shown, to stop the drip from the displaced water. In determining the specific gravity, the dried and cooled sample is weighed to the nearest 0.5 gm. and immersed in water for 24 hours. The pieces are then individually surface-dried with a towel, the sample reweighed and immediately placed in the cylinder, which has been filled previously to overflowing with water at room temperature.

The weight of water displaced by the sample is used to calculate its apparent specific gravity. The difference between the original weight of the sample and its weight after 24 hours, is used to determine the absorption.

Abrasion Test for Gravel.—The aggregate is screened first through screens having circular openings 2 in., 1½ in., 1 in., ¾ in. and ½ in. in diameter. The sizes used for this test are divided equally between those passing the 2 in. and retained on a 1½-in. screen, passing a 1½-in. screen and retained on 1-in. screen, passing a 1-in. screen and retained on a ¾-in. screen, passing a ¾-in. screen and retained on a ½-in. screen. The material of these sizes is washed and dried. The following weights of the dried stone are then taken: 1,250 g. of the size passing the 2 in. and retained on the 1½-in. screen, 1,250 g. of the size passing the 1½ in. and retained on the 1-in. screen, 1,250 g. passing the 1-in. screen and retained on the ¾-in. screen, and 1,250 g. passing the ¾-in. screen and retained on the ½-in. screen. This material is placed in the cast-iron cylinder of the Deval machine, as specified for the standard abrasion test on stone. Six cast-iron spheres 1.875 in. in diameter and weighing approximately 0.95 lb. (0.45 kg.) each, are placed in the cylinder as an abrasive charge. The spheres are the same as those used in the standard paving brick rattler test.

After the cast-iron spheres have been placed in the cylinder the lid is bolted on and the cylinder mounted in the frame of the Deval machine. The duration of the test and the rate of rotation are the same as specified for the standard test for stone, namely, 10,000 revolutions at the rate of 30 to 33 r.p.m. At the completion of the test the material is taken out and screened through a 16-mesh sieve. The material retained upon the sieve is washed and dried and the per cent loss by abrasion of the material passing the 16-mesh sieve calculated.

When the materials have a specific gravity below 2.20 a total weight of 4,000 g., made up of the four groups of sizes described above, instead of 5,000 g. shall be used in the abrasion test.

Proposed Test for Percentage of Shale in Gravel.—It is suggested that for the separation of shale and other light unsatisfactory pieces from concrete aggregate, a solution of zinc chloride ($ZnCl_2$) or some other satisfactory liquid having a specific gravity of approximately 1.95 be used. A sample of the pebbles should be first dried to constant weight at not over 110°C., then placed in a container of suitable size partially filled with the solution. Agitate for 5 min. skim off the lighter materials and then pour the solution through a sieve which will retain the pebbles. Repeat operation until entire sample has been separated. Dry to constant weight, measure the volume of retained material and compute the percentage by volume of shale or other soft material.

Test for Clay in Sand-clay, Top-soil and Semi-gravel.—Dry 500 g. of the material at a temperature below 350°F. (176.6°C.) to a constant weight. Gently pulverize to break down soft clods or masses, but not to grind or break hard material. Pass through a 10-mesh sieve, weigh the coarse residue and record as "coarse material." Use the material passing through the 10-mesh sieve as the starting point of a percentage analysis as follows:

Weigh out two samples of 50 g. of this material for duplicate analysis. Place each in a tared wide mouth bottle (5 to 6 cm. diameter and about 12 to 15 cm. high). Add about

5 c.c. of dilute ammonia water and about 200 c.c. of water. Close with a cork or glass stopper and shake thoroughly for 20 min. Allow the sample to settle 8 min. and decant carefully or siphon off the supernatant liquid to a depth of 8 cm. below the surface of the liquid. (The depth of the liquid in the bottle should be sufficient to leave about 4 cm. below the point of siphoning.) Fill the bottle again with water, shake for 3 min. allow settlement, and siphon off as before. Repeat the process until the supernatant liquid is clear. Be careful to wash the stopper and neck of the bottle free from coarse material before decanting.

Dry bottle and washed material to constant weight at between 100°C. (212 F.) and 110°C. (230°F.), weigh and determine net weight of washed material.

$$\frac{\text{Original weight} - \text{washed weight}}{\text{Original weight}} \times 100 = \text{per cent clay and silt.}$$

As a check the washings drawn off shall be collected and evaporated to dryness for direct recovery of the fine sediment classed as clay and silt.

$$\frac{\text{Weight of residue}}{\text{Original weight}} \times 100 = \text{per cent clay.}$$

The determinations on the two samples shall check within 1 per cent to be acceptable.

Tests for Semi-gravel, Top-soil and Sand-clay.—Wash the contents of the bottle cleanly into a porcelain evaporating dish and carry to dryness on a water bath. The dried residue should be carefully scraped from the dish and passed through a nest of 20-, 60-, 100- and 200-mesh sieves. The residue retained on each sieve is weighed and recorded as sand of the respective sizes. Their sum constitutes the total "sand." The residue passing the 200-mesh sieve and caught in the pan is weighed and recorded as "silt." Duplicate samples should check within 1 per cent.

(*a*) The coarse material should be examined for hardness and with the magnifying glass to identify its character as quartz, hard iron compounds, feldspar, schistose material, or indurated clay. Hard quartz or iron gravels are valuable in themselves and as indicating the quality of the finer aggregate. Feldspar, mica, and clay nodules are worthless and indicate that the accompanying soil is poor for road building.

(*b*) The sands should be examined with the magnifying glass for identification as quartz and for the presence of mica scales or feldspar needles. If mica or feldspar is present in appreciable amounts the sample should be rejected.

(*c*) When the clay is recovered by evaporation it can be examined for tenacity by cementing together two glass plates, each 1 in. wide, set at right angles, with a layer of clay whose thickness is fixed by a fine bent wire laid between the plates. The moist clay covers the wire on one plate, and the other plate is squeezed down tightly on the wire. After drying, the 1 plate held firmly against cleats, wire slings are run symmetrically from the ends of the upper plate to one arm of a beam balance, and the tension necessary to separate the plates is given by shot or weights in the other pan of the balance. This test is tedious and is of service chiefly on low-grade samples which are of doubtful efficiency, but which represent the only available material for local construction.

(*d*) Approximate tests for tenacity of mixture can be made as follows:

Make cylinders from the material passing the 10-mesh sieve, 25 mm. The material is worked into a stiff mud and molded under 132 kg. per square centimeter pressure. Dry thoroughly at 100°C. (212°F.) and break by the small Page impact machine for testing cementing value, using a 1-kg. hammer and 1-cm. drop. Record the number of strokes as the relative measure of tenacity.

Usually the plastic character and adhesiveness of a good road soil can be judged by the feeling of the mud made from this material, its adherence to the hands, and its stretch under light pulling.

NEW JERSEY SPECIFICATIONS

91. Requirements Governing Materials

91A. General Conditions Governing Their Use.

No materials shall be used which do not conform with the requirements therefor as herein defined. All materials used in the construction of any of the items of work given in the Estimate of Quantities or in any additional or extra work that may be performed by the Contractor, as herein provided, shall be furnished by the Contractor. The materials required for the different items of construction are given under said items. The requirements governing the use of patented materials, products or processes are given in Article 14. Samples of acceptable materials are on file at the Laboratory of the Department, Taylor and Quarry Place, Trenton, New Jersey, and will be shown to prospective bidders upon request. No materials shall be used until tested and released by the Testing Engineer.

Railroad cars or barges, used for transporting such road materials as stone, gravel, slag, sand, bituminous filler, Portlandcement, bituminous cement, oils, tars, etc., must be clean when any of these road materials are deposited therein. Materials shipped in cars, the sides or bottoms of which are coated with coal dust, manure, ashes, clay, loam, earth, hay, straw, etc., will be rejected regardless of the quality of said materials. Railroad cars containing broken sides or bottoms must be repaired before any materials are deposited therein.

Trucks, wagons or other vehicles used in hauling or transporting road materials must be kept clean, in proper working condition, have strong, substantial bodies which will prevent materials from escaping therefrom during transit, and be approved by the Engineer before being used.

Materials which have been approved before shipment and are injured in transit, during unloading or handling at the site of the work, shall not be used until reapproved. During handling of all stone, sand or other materials which are to be used in concrete extra care must be taken that no earth or subgrade gets mixed therewith.

All bituminous cements shall be shipped ready for use without further fluxing at the mixing plant or roadside. Each carload of bituminous or Portland cement must be sampled and released before being used. Such samples may be taken before shipment under special arrangement in each case with the Department, or, in default thereof, must be taken by the Engineer or Inspector on arrival at the terminal nearest the work, or at any other convenient point. Carloads of stone, sand, gravel and bituminous paving mixtures shall be carefully examined by the Inspector, but shall not be unloaded until released by him. Materials appearing defective shall be sampled and held until the sample taken has been tested by the Testing Engineer. Any material condemned by the Engineer shall be removed at once from the roadway.

Cement and other materials liable to damage from the elements by exposure must be stored in proper structures which will prevent them from becoming damaged. The method of storing and handling explosives and highly inflammable materials will be governed by the local regulations therefor.

The quantities of materials required shall be determined by weight unless otherwise specified. The railroad shipping weights shall govern in deciding the actual amount furnished or used. The Contractor, when requested, shall furnish the Department with the freight bills of all materials received.

91B. Conditions Governing Approval of Materials.

No materials will be approved for use which do not comply with the requirements given therefor. The approval of a given material is in effect only as long as the material supplied is of the same character and composition as the sample approved. The approval of a material for a particular purpose or for use in a specified manner does not approve its use for any other purpose or manner.

91C. Methods Used in Testing Materials.

The methods to be used in testing the materials given herein are those on file at the office of the Department at Trenton, and will be furnished to producers or manufacturers upon application.

92. Broken Stone

All broken stone, regardless of type, must not contain more than five (5) per cent of weathered or partly decomposed rock. When used in concrete or to be coated with a bituminous material it must be free from pieces coated or partly coated with mud, clay, loam or other foreign material, and must not contain any other type of stone having a higher per cent of wear than that specified for the stone itself. All such stone must be shipped in clean cars. Stone shipped in dirty cars will be rejected. Any one given type of broken stone, as shipped, must not contain over ten (10) per cent of any other type of stone. Approved stone of different types cannot be mixed during use, nor used intermittently for any one given item of construction. All orders for crushed or broken stone must state purpose for which it is to be used.

All stone must not contain more than five (5) per cent of slabs, flat or elongated pieces, the width of which is less than five (5) per cent of the length. The various stone fragments composing any particular size shall be uniformly distributed throughout the mass of stone, as shipped. When two (2) or more sizes of stone are mixed to secure any particular specified size, the mixing must be done before the stone is loaded into the shipping vehicle. The following methods are suggested:

Simultaneously feeding on belt conveyor proper proportions of the different sizes.

Feeding proper proportions of the different sizes through converging chutes into the bin or stock pile from which the material is to be shipped,

Reversing screen plates or other arrangement of screens, which will insure a properly graded material of the sizes desired.

Shipments containing pies or layers of broken stone that are not uniform will be rejected.

Stone intended for use in any Portland cement concrete or to be coated with a bitumen, in addition to meeting the above requirements, must not contain more than ten (10) per cent of stone coated or partly coated with stone dust. Stone which has become coated with mud, loam, clay or other foreign material, either during transit or after receipt on site of work, must not be used and shall be removed from the highway or storage site.

92A. Sizes.

Permissible variations as to size of stone are shown in the table below for each size and grade of stone. This table shows the minimum and maximum allowable percentages passing the different screens and sieves. The screens and sieves designated in the table are those used in the laboratory of the Department.

Whenever the words Trap, Granite, Dolomite, Limestone Gneiss, Sandstone or Quartzite are used in these specifications, the rocks designated thereby shall comply with the following additional requirements respectively.

Trap Rock: A basic igneous rock consisting principally of augite and plagioclase. It must be of medium or fine grain texture, show an even distribution of the constituent minerals, be of uniform quality and structure throughout, and have a per cent wear not greater than three (3).

Granite: An igneous rock consisting principally of quartz and feldspar. It shall be of medium or fine grain texture, show an even distribution of the constituent minerals, be of uniform quality and texture throughout, and have a per cent wear not greater than four and one-half (4.5).

Dolomite: A rock consisting principally of the carbonates of lime and magnesia. It must contain not less than thirty (30) per cent of magnesium carbonate, nor less than eighty (80) per cent of the combined carbonates of lime and magnesia. It must be of uniform quality and texture throughout, have a per cent wear not greater than 3.5 and be of such density that it will not be noticeably affected by five (5) immersions in a saturated solution of sodium sulphate with proper dehydration after each immersion.

Limestone: A rock consisting principally of the carbonates of lime and magnesia. It must contain not less than fifty-five (55) per cent of calcium carbonates, nor less than eighty (80) per cent of the combined carbonates of lime and magnesia, have a per cent wear not greater than six (6), and be of such a density that it will not be noticeably affected by five

TOTAL PER CENT PASSING

Grades and sizes	Laboratory screens, inches								Sieves		
	3½	3	2¼	1½	1¼	¾	½	¼	10	30	200
2½-in. "Ballast"	100	90–100	0–25	...	0–5						
Concrete stone	...	100	95–100	...	25–60	0–15	0–5				
1½-in. Stone	...	100	95–100	...	0–15	0–5					
¾-in. Stone	...	.....	.....	100	95–100	0–25	0–5				
Screenings—Grade A,[1]	...	.....	.....	...	100	95–100	50–85	35–70	.....	10–30	0–5
Screenings—Grade B	...	.....	.....	...	100	95–100	.....	40–80	.....	25–65	5–20
Dustless screenings	...	.....	.....	...	100	95–100	25–75	0–25	0–5		
Stone dust—Grade A,[2]	...	.....	.....	...	.....	.....	100	95–100	70–90		
Stone dust—Grade B	...	.....	.....	...	.....	100	95–100	90–100			

[1] Screenings Grade A shall be made from recrushed stone only.

[2] Stone dust Grade A shall be made from recrushed stone only.

It is suggested that stone crushing plants be equipped with the following screens: 3½, 3, 2¼, 1¼, ¾ in., and a dust jacket with 5/16-in. openings if round, or ¼-in. if square. If any special sizes of stone are required, additional screens will be needed.

The type and size of broken stone required for the different items of construction are specified under said items.

(5) immersions in a saturated solution of sodium sulphate with proper dehydration after each immersion.

Gneiss: A rock containing practically the same minerals as granite, but having these minerals arranged in strata. It must have a dense structure with the lines of stratification not so distinctly formed that the stone breaks in thin pieces or slabs. It must have a per cent wear not greater than four and one-half (4.5).

Sandstone or Quartzite: A rock belonging to either of these two types shall contain not less than ninety (90) per cent of quartz, be of uniform quality and texture, free from seams, lines of clay, distinct cleavage planes, or lines of stratification which will cause the stone to break into thin slabs or pieces. It must have a per cent wear not greater than four and one-half (4.5).

93. Slag

All slag must be air cooled, have a fresh, clean surface, free from mud, dirt, clay or loam. It must not be brittle nor glassy nor have an apparent specific gravity greater than 3.0 at 15.5°C. When used for concrete it must produce a concrete which will have an average compressive strength of not less than 4,000 lb. per square inch when twenty-eight (28) days old, havingthe same composition and consistency, and tested in the same manner given here in under "Broken Stone." It must weigh not less than seventy (70) pounds per cubic foot loose measure, and be free from decomposed products. The requirements governing the different sizes will be the same as for broken stone. Slag containing more than one and one-half (1½) per cent of sulphur shall not be used in reinforcement concrete.

94. Gravel

Gravel shall be divided into two general classes: Washed gravel and road gravel.

94A. WASHED GRAVEL.

Washed gravel may be composed partially or totally of crushed pebbles, but must be

free from soft, thin, elongated pieces, organic matter, loam, clay, or pebbles coated therewith. It shall contain only pebbles of a sound, hard, durable character, and must be uniform in composition, free from weathered, decomposed pebbles, pieces of coal or other foreign materials. It shall not contain more than 5 per cent of slate, shale or soft sandstone particles, having a per cent wear greater than.....

When tested by means of laboratory screens and sieves the various sizes of washed gravel shall conform to the following requirements:

TOTAL PER CENT PASSING

Sizes	Laboratory screens, inches					Sieves
	2¼	1½	1¼	½	¼	10-mesh
1½ in.	100	...	0–25	0–5		
¾ in.	...	100	75–100	0–25	0–5	
Concrete gravel[1]	100	...	25–50	0–12	0–2	
Pea gravel	...	...	100	95–100	0–25	0–5

[1] Concrete Gravel size may be prepared by mixing two (2) parts of one and one-half (1½) inch gravel with one (1) part of three-quarter (¾) inch gravel by volume; however, when thus prepared, these two sizes must be mixed in such a manner that will insure a uniformly graded product, conforming to the screen requirements given below. The method employed in mixing in each case must be approved by the Department before using.

94B. ROAD GRAVEL.

Road gravel shall be composed of sand and hard, durable pebbles of quartz, mixed with clay in such proportions that the gravel will comply with the grading and other requirements specified herein below, and also compact under travel into a hard, dense pavement. It shall contain not less than eight (8) nor more than twenty (20) per cent by weight of material removed by the elutriation test, and the gravel having the fine material thus removed shall, when tested by means of laboratory screens and sieves, comply with the requirements given below:

TOTAL PER CENT PASSING

Grades	Screens, inches					Sieves
	2	1½	1	½	¼	10
A	100	95–100	85–100	55–90	45–80	35–70
B	...	100	95–100	90–100	75–95	60–85

95. Sands

Sands shall consist of grains or particles of quartz or other hard and durable rocks, the surfaces of which are not coated with any foreign material nor worn smooth. The grains shall be moderately sharp, free from soft, decomposed or partly decomposed sand grains, lumps of clay, or ferruginous cemented sand, mica, loam, sea salts, organic matter, or other materials.

Sands shall be divided into two general classes, bituminous sands and concrete sands.

95A. Bituminous Sands.

Bituminous sands are those intended for use in the construction of bituminous pavements, bituminous mortars, bituminous fillers, or mastics, and when tested by means of laboratory screens and sieves shall conform to the following requirements:

Passing	Retained on	Minimum, Per Cent	Maximum, Per Cent
¼-in. screen	10-mesh sieve	0.0	2.0
10-mesh sieve	30-mesh sieve	10.0	30.0
30-mesh sieve	50-mesh sieve	15.0	42.0
50-mesh sieve	80-mesh sieve	20.0	35.0
80-mesh sieve	200-mesh sieve	15.0	35.0
200-mesh sieve	.....	....	5.0

95B. Concrete Sands.

Concrete sands are those intended for use with Portland cement either in a Portland cement concrete or mortar, and when tested by means of laboratory screens and sieves should conform to the following requirements:

Passing	Retained on	Minimum, Per Cent	Maximum, Per Cent
½-in. screen	¼-in. screen	....	1.0
¼-in. screen	10-mesh sieve	5.0	25.0
10-mesh sieve	30-mesh sieve	30.0	60.0
30-mesh sieve	50-mesh sieve	20.0	40.0
50-mesh sieve	200-mesh sieve	5.0	15.0
200-mesh sieve	.....	....	5.0

Concrete sands must not contain more than four (4) per cent of material removed by the elutriation test and must produce a Portland cement mortar which will have at the end of seven (7) and twenty-eight (28) days a crushing and tensile strength equal to or greater than that of a mortar prepared in the same manner, of the same proportions and consistency, using the same cement, and Standard Ottawa sand. The ratio of cement to sand is to be the same as that specified for the concrete in which said sand is to be used. The approval of a sand for use in concrete of a given composition does not approve its use in concrete having a different composition.

95C. Stone Dust.

Stone dust, Grade A, may be used as a concrete sand, but only after being approved by the Engineer for this purpose, said approval shall apply only to the material that is actually represented by the sample. It must produce a mortar having not less than one hundred and twenty-five (125) per cent of the strength of a similar mortar prepared from Ottawa sand and tested in the same manner as "Concrete Sands."

95D. Grout Sand.

Sands intended for use in a Portland cement grout must, in addition to meeting the other general requirements given above, all pass a 10-mesh sieve and produce a Portland cement mortar which will have at least seventy-five (75) per cent of the strength of a similar mortar prepared with Standard Ottawa sand, and tested in the same manner as "Concrete Sands."

95E. Cushion Sand.

Sands for use in the cushion course placed under paving blocks shall comply with the requirements for a concrete sand except the mortar produced therefrom need only 75 per cent of the strength of a similar mortar prepared from Standard Ottawa sand and tested in the same manner as specified under "Concrete Sand."

96. Portland Cement

This cement shall comply with the requirements and be tested in the manner specified by the American Society for Testing Materials, Serial Designation C9–21, with all subsequent changes or corrections.

All Portland cement required for use will be shipped from bins previously approved by the State Highway Department. Copies of all Portland cement orders, placed by the Contractor with cement companies, direct or through brokers or local dealers, shall be forwarded to the Department. When an order is placed through a broker or local dealer, said broker or local dealer shall furnish the Department with a copy of this order to the cement company for the cement required. In all cases, regardless of whether the cement is ordered by the Contractors direct or through brokers, the order must be placed with the cement company at least ten (10) days previous to the date of the initial shipment. The extra cost, if any, required for shipment from previously approved bins shall be borne by the Contractor and will not be paid for by the Department.

All Portland cement shall be shipped in cloth bags, which are plainly stamped with the manufacturer's name and brand of cement contained therein. Each bag shall contain ninety-four (94) pounds of cement net weight and be considered as containing one (1) cubic foot of cement.

Bags of cement which for any reason have become partially set on the outside or which contain lumps or partly set cement, shall be rejected.

Different brands, makes or grades of cement, must be piled by themselves. Approved cements cannot be mixed during use, or used intermittently in any one given item of construction.

All cement must be stored in bins prepared for this purpose and shipment made only from these bins. All cars shall be loaded under the supervision of and sealed by a representative of the State Highway Commission. Cars received at their point of destination with seals broken or destroyed may be unloaded, but should not be used until resampled and approved.

Producers are requested not to permit shipments to be made of any cement that does not comply with the requirements given. It is assumed that all cement shipped complies with the requirements given herein. All shipments made containing cement that does not comply with the requirements given herein shall be replaced with cement that does comply with said requirements.

Water used with Portland cement shall be clean, free from oil, acid, alkali, sea salts or vegetable matter.

97. Mineral Fillers

Fillers for use in a bituminous mortar, bituminous concrete, or sheet asphalt shall be Portland cement, ground limestone or pulverized lime not less than eighty-five (85) per cent of which must pass a one hundred (100) mesh sieve and sixty-five (65) per cent a two hundred (200) mesh sieve. It shall be free from lumps or balls, or any foreign material that may injure it for the purpose intended.

98. Bituminous Cement

Must be uniform, homogeneous and free from water. They must pass the requirements designated below for the respective type of pavement for which they are intended to be used. They must have the consistency required herein before shipping, for fluxing will not be allowed at the mixing plant.

99. Asphaltic Cements and Oils

Asphaltic cements may be made from petroleum or from fluxed or unfluxed natural asphalts, and must be free from tar or tar products.

99A. Prepared from Natural Asphalts.

Grades	NA–1		NA–2		NA–3		NA–4		NA–5	
Tests	Min.	Max.	Min.	Max.	Min.	Max.	Max.	Max.	Min.	Max.
1. Specific gravity at 15.5°C	1.045	.....	1.045	.....	1.04	.....	1.04			
2. Penetration at 25°C., 100 g.—5 sec.	40	50	50	60	75	95	90	150	10	20
3. Penetration at 46°C., 50 g.—5 sec.	.....	.....	.....	.....	.....	.....	.....	.....	.....	80
4. Evaporation loss at 163°C., 20 g. —5 hour, per cent	1.50	3.0	1.50	3.00	1.50	3.50	1.50	4.0	.....	3.0
(*a*) Penetration on residue at 25°C., 100 g.—5 sec	20	.....	25	.....	35	.....	45	.....	5	
5. Solubility in benzol, C_6H_6, per cent	95.00	98.00	95.00	98.00	95.00	98.00	95.00	98.00		
6. Bitumen soluble in ether, $(C_2H_6)_2O$ per cent	85.00	.....	85.00	.....	85.00	.....	85.00			
7. Bitumen Soluble in carbon tetrachloride, CCl_4, per cent	99.00	.....	99.00	.....	99.00	.....	99.00			
8. Flash point in °C	175	.....	175	.....	175	.....	165	.....		
9. Ductility at 50 penetration (cm.)	50.0	.....	50.0	.....	50.0	.....	50.0		25.0[1]	
10. Paraffin scale										

[1] Taken at 20 penetration.

99B. Petroleum Residua Prepared from Heavy Mexican Petroleum.

Grades	H.M.[1]		H.M.[2]		H.M.[3]		H.M.[4]			
Tests	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.
1. Specific gravity at 15.5°C	1.04	.....	1.035	.....	1.035	.....	1.03			
2. Penetration at 25°C., 100g.—5 sec.	45	55	55	65	75	95	90	150		
3. Penetration at 46°C., 50 g.—5 sec.	.....	300	.....	360						
4. Evaporation loss at 163°C., 20 g. —for 5 hour, per cent	.....	1.00	.....	1.00	.....	1.50	.....	1.50		
(*a*) Penetration on residue at 25°C., 100 g.—5 sec	30	.....	35	.....	45	.....	50			
5. Solubility in benzol, C_6H_6, per cent.	99.80	.....	99.80	.....	99.80	.....	99.80			
6. Solubility in ether, $(C_2H_6)_2O$, per cent	75.00	.....	75.00	.....	75.00	.....	75.00			
7. Solubility in carbon tetrachloride, CCl_4, per cent	99.00	.....	99.00	.....	99.00	.....	99.00			
8. Flash point in °C	225	.....	215	.....	210	.....	200			
9. Ductility at 50 penetration (cm.)	100	.....	90	.....	80	.....	70			
10. Paraffin scale, per cent	.....	1.25	.....	1.25	.....	1.50	.....	1.75		

99C. Petroleum Residua Prepared from Light Mexican Petroleum.

Grades	L.M.[1]		L.M.[2]		L.M.[3]		L.M.[4]			
Tests	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.
1. Specific gravity at 15.5°C.	1.035	.....	1.030	.....	1.030	.....	1.025			
2. Penetration at 25°C., 100 g.—5 sec..	45	55	55	65	75	95	90	150		
3. Penetration at 46°C., 50 g.—5 sec..	.....	300	.....	360						
4. Evaporation loss at 163°C., 20 g.. —for 5 hour, per cent.	.....	1.00	.....	1.00	.....	1.50	.....	1.50		
(a) Penetration on residue at 25°C., 100 g.—5 sec.	30	.....	35	.....	45	.....	50			
5. Solubility in benzol, C_6H_6, per cent.	99.80	.....	99.80	.....	99.80	.....	99.80			
6. Solubility in ether, $(C_2H_5)_2O$, per cent.	75.00	.....	75.00	.....	75.00	.....	75.00			
7. Solubility in carbon tetrachloride, CCl_4, per cent.	99.00	.....	99.00	.....	99.00	.....	99.00			
8. Flash point in °C.	225	.....	215	.....	210	.....	200			
9. Ductility at 50 penetration (cm.).	100	.....	90	.....	80	.....	70			
10. Paraffin scale, per cent.	.....	3.50	.....	3.75	.....	4.00	.....	4.50		

99D. Petroleum Residua Prepared from California Petroleum.

Grades	C.[1]		C.[2]		C.[3]		C.[4]			
Tests	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.
1. Specific gravity at 15.5°C.	1.025	..	1.02	.....	1.02	.....	1.015			
2. Penetration at 25°C., 100 g.—5 sec.	40	50	50	60	70	90	90	150		
3. Penetration at 46°C., 50 g.—5 sec.										
4. Evaporation loss at 163°C., 20 g.—for 5 hour, per cent	.....	.75	.....	1.00	.....	1.25	.....	1.50		
(a) Penetration on residue at 25°C., 100 g.—5 sec.	20	..	25	.....	30	.....	35			
5. Solubility in benzol, C_6H_6, per cent.	99.80	..	99.80	.....	99.80	.....	99.80			
6. Solubility in ether $(C_2H_5)_2O$, per cent.	85.00	..	85.0	.....	87.0	.....	89.00			
7. Solubility in carbon tetrachloride, CCl_4, per cent..	99.00	..	99.00	.....	99.00	.....	99.00			
8. Flash point in °C.	210	..	205	.....	200	.....	175			
9. Ductility at 50 penetration (cm.)	150.0+	..	150.0+	.....	150.0+	.....	150.0			
10. Paraffin scale										

99E. Petroleum Residua Prepared by Blending California and Mexican Residua.

Grades	C.M.[1]		C.M.[2]		C.M.[3]		C.M.[4]			
Tests	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.
1. Specific gravity at 15.5°C	1.03	.....	1.025	.....	1.02	.....	1.02			
2. Penetration at 25°C., 100 g.—5 sec.	45	55	55	65	75	95	90	150		
3. Penetration at 46°C., 50 g.—5 sec.										
4. Evaporation loss at 163°C., 20 g. —for 5 hour, per cent	.....	1.00	.....	1.00	.....	1.50	.....	1.50		
(a) Penetration on residue at 25°C., 100 g.— 5 sec.	25	.....	30	.....	40	.....	45			
5. Solubility in benzol, C_6H_6, per cent.	99.80	.....	99.80	.....	99.80	.....	99.80			
6. Solubility in ether, $(C_2H_5)_2O$, per cent	80.0	.....	80.0	.....	82.0	.....	83.0			
7. Solubility in carbon tetrachloride, CCl_4, per cent	99.00	.....	99.00	.....	99.00	.....	99.00			
8. Flash point in °C	220	.....	215	.....	205	.....	190			
9. Ductility at 50 penetration (cm.)	125.0	.....	125.0	.....	100.0	.....	100.0			
10. Paraffin scale, per cent	.....	2.25	.....	2.25	.....	2.50	.....	2.75		

99F. Petroleum Residua Prepared by Blending Mexican and Semi-asphaltic Base Petroleums.

Grades	T.[1]		T.[2]		T.[3]		T.[4]			
Tests	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.
1. Specific gravity at 15.5°C	1.00	...	1.00	...	1.00	...	1.00			
2. Penetration at 25°C., 100 g.—5 sec	45	55	55	65	75	95	90	150		
3. Penetration at 46°C., 50 g.—5 sec.	.....	275	.....	325						
4. Evaporation loss at 163°C., 20 g. —for 5 hours, per cent	.....	1.0	.....	1.0	.....	1.0	.....	1.0		
(a) Penetration on residue at 25°C., 100 g.—5 sec.	30	...	35	...	45	.....	50			
5. Solubility in benzol, C_6H_6, per cent	99.5	...	99.50	...	99.5	...	99.5			
6. Solubility in ether, $(C_2H_5)_2O$, per cent	70.0	...	70.0	...	70.0	...	70.0			
7. Solubility in carbon tetrachloride, CCl_4, per cent	99.0	...	99.0	...	99.0	...	99.0			
8. Flash point in °C	175	...	175	...	175	...	175			
9. Ductility at 50 penetration (cm.)	30.0	. .	30.0	...	30.0	...	30.0			
10. Paraffin scale										

99G. Asphalt Cement Emulsion.

1. *General:* The emulsion shall be homogeneous, of such character that it will mix with water in all proportions and of such stability that it will remain constant and uniform while being combined and mixed with clean, wet, crushed stone. Its consistency shall be such as uniformly to coat the stone and remain constant while being handled.

2. *Stone Test:* One (1) pound of dry, clean, trap rock screenings, Grade A, shall be washed until clean and surplus water allowed to drain off for a period of five (5) minutes.

To this clean, washed, crushed stone screenings shall be added one and one-quarter ($1\frac{1}{4}$) ounces of the emulsion. The mixture will then be constantly agitated by stirring, turning and mixing for a period of three (3) minutes.

Any material that will not retain its emulsified characteristics without appreciable separation during such agitation will be rejected as being unsuited for the purpose for which it is intended.

3. *Analysis of Emulsion:* When distilled up to a temperature of 260°C. the total loss shall not exceed thirty-two (32) per cent and not more than two (2) per cent of this distillate shall be other than water. The residue from the foregoing distillation shall comply with the following requirements:

Grade	A.E.					
Tests	Min.	Max.	Min.	Max.	Min.	Max.
1. Specific Gravity at 25° C.....	1.01					
2. Penetration at 25°C., 100 g.—5 sec.	150	250				
3. Solubility in CS_2, per cent.....	98.5					
4. Fixed carbon, per cent.....	6.0	15.0				
5. Ash, per cent.....	.....	1.0				
6. Ductility at 25°C. (cm.).....	40.0					
7. Paraffin scale, per cent.....	.....	4.7				

99H. Asphaltic Oils.

Nature of oils	Dust oil		Slow curing oil		Rapid curing oil		Cut back light		Cut back heavy		Hot oil light		Hot oil heavy	
Grades	D.O.		S.C.O.		R.C.O.		L.K.		H.K.		L.H.O.		H.H.O.	
Tests	Min	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.
1. Specific gravity at 15.5.°C	0.92	.....	0.93	.....	0.90	.....	.....	.....	.....	.....	0.95	.....	1.00	
2. Evaporation loss on 20 g. at 163°C.—for 5 hours, per cent	8.0	25.0	12.0	.....	20.0	.....	35.0	.....	30.0	.....	5.0	12.0	.....	5.0
(*a*) Penetration on residue at 25°C., 100 gm.—5 sec	.....	.....	.....	.....	75	.....	45	90	45	90				
(*b*) Float test at 50°C. (seconds)	10	30	20	.....	150									
3. Evaporation loss on 20 g. at 100°C.—for 5 hours, per cent	.....	3.0	4.0	15.0	10.0	.....	25.0	.....	20.0					
	25°C.		46°C.		46°C.		25°C.		25°C.		90°C.		90°C.	
4. Viscosity—temperature (1st 50 c.c., Engler)—seconds	225	450	175	300	275	450	180	325	600	1,200	300	600	600	1,200
5. Solubility in benzol, C_6H_6, per cent	99.5	.....	99.5	.....	99.5	.....	99.5	.....	99.5	.....	99.5	.....	99.5	
6. Ductility, at 50 penetration (cm.)	.....	.....	.....	.....	20.0	.....	70.0	.....	70.0	.....	20.0	.....	20.0	
7. Asphaltic content at 100 penetration, per cent	40.0	50.0	50.0	65.0	60.0	75.0	55.0	65.0	60.0	70.0	75.0	85.0	85.0	95.0
8. Flash point in °C	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	140	.....	160	

100. Tars

Tar may be either coal tar or petroleum water gas tar. They must comply with the following requirements:

100A. Coal Tars.

Grades	A		B		X		KP					
Tests	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.
1. Water content, per cent	.....	0.00	.....	2.0	.....	0.00	.....	2.0				
2. Specific gravity at 15°C	1.20	1.28	1.12	1.18	1.22	1.30	1.15	1.20				
3. Float test at 50°C. in seconds	35	75										
4. Melting point (B. & R.), °C	.....	.....	.....	.....	30	36						
5. Viscosity Engler at 40°C., first 50 c.c. (seconds)	.....	.....	100	150								
6. Viscosity, Engler at 80°C., first 50 c.c. (seconds)	.....	.....	.....	.....	.....	.....	40	60				
7. Free carbon, per cent	12.0	20.0	4.0	12.0	12.0	25.0	12.0	25.0				
8. Distillation 0°C.—170°C., per cent	.....	0.1	.....	7.0	.....	0.1	.....	10.0				
9. Distillation 0°C.—235°C., per cent	.....	10.0	.....	18.0	.....	3.0	.....	23.0				
10. Distillation 0°C.—270°C., per cent	.....	18.0	.....	30.0	.....	12.0	.....	27.0				
11. Distillation 0°C.—300°C., per cent	.....	28.0	.....	35.0	.....	15.0	.....	32.0				
12. Specific gravity of entire distillate	1.02	.....	1.01	.....	1.03	.....	0.98					
13. Melting point of distillation residue												

100B. Water Gas Tars.

Grades[1]	UA		UB		UC		UD		U[2]		U[3]		U[4]	
Tests	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.
1. Specific gravity at 25°C	1.09	1.13	1.10	1.14	1.09	1.145	1.110	1.155	1.14	1.18	1.15	1.185	1.16	1.19
2. Float test at 50°C. (sec.)	.....	.....	.....	.....	.....	.....	.....	.....	50	75	80	110	115	145
3. Viscosity at 40°C., 1st 50 c.c.—Engler (sec.)	80	120	250	350	400	500	700	800						
4. Free carbon (using CS_2 cold), per cent	.....	5.0	.....	5.0	.....	5.0	.....	5.0	.....	5.0	.....	5.0	.....	5.0
5. Distillation—Total up to 170°C., per cent	.....	3.0	.....	2.0	.....	3.0	.....	2.0	.....	*Nil.*	.....	*Nil.*	.....	*Nil.*
6. Distillation—Total up to 235°C., per cent	.....	18.0	.....	15.0	.....	20.0	.....	18.0	.....	4.0	.....	3.0	.....	2.0
7. Distillation—Total up to 270°C., per cent	.....	35.0	.....	30.0	.....	30.0	.....	28.0	.....	13.0	.....	11.0	.....	9.0
8. Distillation—Total up to 300°C., per cent	.....	45.0	.....	40.0	.....	40.0	.....	38.0	.....	26.0	.....	22.0	.....	18.0
9. Melting point of distillation residue (B. & R.), °C	.....	60	.....	60	.....	60	.....	60	.....	65	.....	65	.....	65

[1] Grades UA, UB, UC and UD are to be prepared by cutting back U[3] with a suitable distillate.

LEGEND OF ASPHALTIC CEMENTS, ASPHALTIC OILS AND TARS

Intended use	Grades that may be specified
Sheet asphalt, type S. A	N. A.–1, H. M.–1, L. M.–1, C–1, C. M.–1, or T.–1
Bituminous concrete surfaces, mixed hot, Type F. A.–B. C.–1, F. A.–B. C.–2, or W–B	N. A.–2, H. M.–2, L. M.–2, C–2, C. M.–2, or T.–2
Bituminous concrete surfaces, mixed cold, type A	N. A.–3, H. M.–3, L. M.–3, C–3, C. M.–3, or T.–3
Bituminous macadam surfaces, penetration method	N. A.–4, H. M.–4, L. M.–4, C–4, C. M.–4, T–4, X., or U–4
Patch work, hot mixing method	H. H. O., X., or U–4
Patch work, cold mixing method	L. K., H. K., P., or U. C
Surface treatments, cold application—macadam	S. C. O., R. C. O., B., U. B., or U. C
Bituminous concrete	L. K., or H. K
Surface treatment, hot application—macadam	L. H. O., H. H. O., A., or U–2

101. Bituminous Waterproofing Compounds

All bituminous water-proofing paints shall be prepared ready for use before shipment and shall be shipped in strong, substantial containers, plainly marked with the name and weight of content and name and address of the manufacturer. When so requested, the analysis of all paints furnished must be supplied by the manufacturer within ten (10) days after request is made.

101A. TAR PAINTS.

Tar paints shall be prepared from a refined coal-tar or water-gas tar and a tar distillate. They shall be free from water, or petroleum distillates, and must comply with the following requirements:

Grades	T P–1		T P–2		T P–2	
Tests	Min.	Max.	Min.	Max.	Min.	Max.
1. Viscosity at 25°C., 1st 50 c.c. Engler (seconds)	325	400	275	350	275	350
2. Free carbon (using hot benzol, C_6H_6), per cent	8.0	14.0	12.0	18.0	4.0	10.0
3. Distillation 0°—170°C., per cent	20.0	28.0	12.0	20.0	12.0	20.0
0°—235°C., per cent	0.0	37.0	15.0	35.0	15.0	35.0
0°—270°C., per cent	0.0	39.5	0.0	39.5	0.0	41.0
0°—300°C., per cent	0.0	41.5	0.0	43.5	0.0	46.0
4. Melting point of distillation residue (Ball & Ring) °C	60	70	55	70	55	70

101B. ASPHALTIC PAINTS.

Asphalt paints shall be prepared from petroleum residue or natural asphalts, and a petroleum or tar distillate. They shall be free from water, animal or vegetable oils, fats or greases, and shall comply with the following requirements:

	A P–1					
	Min.	Max.	Min.	Max.	Min.	Max.
1. Evaporation loss at 163°C. on 20 g. for 5 hours, per cent	45.0					
(a) Penetration on residue at 25°C. (100 g.—5 sec.)	10	20				
2. Evaporation loss at 100°C. on 20 g. for 5 hours, per cent	35.0					
3. Solubility in benzol, C_6H_6						
(Prepared from petroleum asphalt), per cent	99.5					
(Prepared from natural asphalt), per cent	95.0					
4. Ductility at 50 penetration at 25°C., centimeters	20.0					
5. Viscosity at 25°C. (Engler, 1st 50 c.c.), seconds,	200	300				
6. Asphaltic content at 100 penetration, per cent	50.0	60.0				

102. Wood Preservatives

Wood preservatives used in the pressure treatment of wooden blocks, piling, etc., shall be either an oil distillate from coal-gas tar, coke-oven tar, or a product of which at least sixty-five (65) per cent shall be a distillate of coal-gas tar or coke-oven tar, and the remainder shall be refined or filtered coal-gas tar or coke-oven tar. Only one type of preservative shall be used on any one contract. They must comply with the following requirements as given under W P–1 and W P–2.

Wood preservatives used in the open-tank treatment of guard rail posts or other timbers shall be an oil obtained by distillation from coal tar or coke-oven tar, and shall be free from any admixture of undistilled tar, water-gas tar, or tars or oils obtained from any other sources. The oil shall conform to the following specifications given under W P-3.

Grades	W P–1		W P–2		W P–3	
Tests	Min.	Max.	Min.	Max.	Min.	Max.
1. Water content, per cent	.....	3.0	.....	3.0	.....	1.0
2. Solubility in benzol, C_6H_6, per cent	99.5	...	97.0	...	99.75	
3. Specific gravity at 38°C./38°C., per cent	1.06	...	1.07	1.14		
4. Specific gravity at 38°C./15°C.	.....	...	.....	...	1.09	1.13
5. Distillates (based on water-free oil), 0°C.—210°C., per cent.	.....	5.0	.....	5.0		
6. Distillates (based on water-free oil), 0°C.—235°C., per cent.	.....	15.0	.....	25.0	.....	2.50
7. Distillates (based on water-free oil), 235°C.—300°C., per cent	.....	...	.....	...	.....	20.0
8. Float test at 70°C. on distillation residue above 355°C., if over 10 per cent, inches	.....	50				
9. Float test at 70°C., on distillation residue above 355°C., if over 35 per cent, inches	.....	...	.....	80	.....	25
10. Per cent of residue above 355°C	.....	...	.....	...	.....	50.0
11. Specific viscosity, Engler at 20°C. on 200 c.c.	.....	...	.....	...	10	
12. Specific gravity at 38°C./15.5°C. of fraction between 235° and 315°C	1.03	...	1.02			
13. Specific gravity at 38°C./15.5°C. of fraction between 315°C. and 355°C	1.09	...	1.09			
14. Coke residue, per cent	.....	2.0	.....	10.0	...	2.0
15. Tar acids (per cent of total distillates), per cent	.....	...	.....	...	.....	15.0
16. Flash point (Cleveland open cup), °C	.....	...	.....	...	120	
17. Fire point (Cleveland open cup), °C	.....	...	.....	...	165	
18. All to be liquid (no solid), °C	.....	...	.....	...	21	

103. Joint Fillers

The material used in filling joints in pavements, curbs, gutters, etc., shall be divided into two grades, Grade P, poured joint fillers, and Grade M, moulded joint fillers.

The poured joint fillers shall be prepared from either a coal tar or an asphalt cement, complying with the requirements given below.

Moulded joint fillers shall be prepared by impregnating such inert materials as felt, woolen or cotton fiber, paper pulp, sawdust, etc., with a bituminous cement complying with the requirements given below. The inert material may be applied as a layer on the outside of a bituminous sheet, or may be uniformly distributed through the bituminous material. In either case sufficient inert material must be used to prevent the joint from chipping during cold weather.

Moulded joint fillers shall be cast in sheets, the thickness of which shall be the same as the joint width specified, but in no case shall moulded joint fillers be cast in sheets less than one-half ($\frac{1}{2}$) inch nor more than three-quarters ($\frac{3}{4}$) inch thick. When no special width is specified the joints shall be cast in sheets from one-half ($\frac{1}{2}$) inch to five-eighths ($\frac{5}{8}$) inch thick.

All moulded joint fillers to be used in transverse joints in a concrete pavement shall be cast in lengths equal to one-half the width of the pavement, have a width of one-half ($\frac{1}{2}$) inch greater than the thickness of the pavement, have one edge cut to the curvature specified for the crown of the pavement, and have a thickness equal to the width of the joint as above specified. When for use in longitudinal joints in concrete pavements adjacent to curbs, gutters, headers, etc., moulded joints shall be made in the lengths and widths ordered.

The various grades of bitumen used for the fabrication of expansion joint fillers shall comply with the requirements given below.

Grades	M. A.		P. A.		P. T.	
Tests	Min.	Max.	Min.	Max.	Min.	Max.
1. Specific gravity at 25°C	1.00	...	1.00	...	1.22	1.30
2. Penetration at 25°C.—100 g. for 5 sec	25	35	30	40		
3. Penetration at 46°C.—100 g. for 5 sec	...	55	...	70		
4. Melting point (ball and ring) °C	...	...	65	95	36	50
5. Evaporation loss on 20 g. at 163°C. for 5 hours, per cent	...	1.0	...	1.0		
6. Solubility in benzol, C_6H_6, per cent	99.0	...	99.5	...	65.0	80.0
7. Solubility in carbon tetrachloride, CCL_4, per cent	...	...	99.0			
8. Flash point in °C	...	...	200			
9. Ductility at 25°C., centimeters	4.0	...	4.0			
10. Float Test at 100°C	...	...	...	...	55	75
11. Distillation 0°—170°C., per cent	...	...	...	...	...	1.0
Distillation 0°—300°C., per cent	...	...	...	...	...	5.0
12. Free carbon, per cent	...	...	...	...	20.0	35.0

104. Lignin Binders

They must be concentrated liquid extracts from organic matter, uniform in composition, homogeneous, free from mineral oils, asphalts or tars. During concentration the liquors must not be heated above 212°F. They must conform to the following requirements:

Grades	G. N.	
Tests	Min.	Max.
1. Specific gravity at 60°F	1.25	
2. Solubility in cold water, per cent	99.5	
3. Solubility in hot water, per cent	99.5	
4. Evaporation loss at 100°C. to constant weight, per cent	....	55.0
5. Ash content, per cent	....	9.5
6. Free acids, per cent	....	0.5
7. SO_2 content as sulphite, per cent	....	1.0
8. CaO content	....	2.5
9. MgO content, per cent	1.25	
10. Ferric oxide content, per cent	....	0.25

105. Inorganic Binders

This class of binder shall consist of concentrated solutions of soluble alkaline silicates and may contain soluble organic compounds. They shall fulfill the following requirements:

Grades	S. S.		R. M.			
Tests	Min.	Max.	Min.	Max.	Min	Max.
1. Solubility in hot water, per cent	99.0	....	99.5			
2. Specific gravity at 60°F.	1.35	1.40	1.20	1.30		
3. Residue on evaporation at 110°C. to constant weight, per cent	60.0	70.0	30.0	40.0		
4. Silica content of residue, per cent	70.0	80.0	36.0	40.0		

106. Telford Base Stone

This stone shall be prepared from a hard, durable rock, such as trap, granite, gneiss, limestone, etc. In the selection of these stones no decomposed, weathered, shattered or soft stone shall be included. The stone shall be broken nearly rectangular in shape, and of such a width that, after knapping, they will produce a foundation of the required thickness. When no special size is specified the stone shall be so broken that, after knapping and trimming up, they will be approximately eight (8) inches in depth, not less than two (2) or more than (5) inches in width, and from six (6) to twelve (12) inches in length.

107. Cobble Stones

Cobble stones shall be composed of only good, hard, durable stone which are nearly uniform in size. They shall not exceed five (5) inches in their largest diameter, except for the center line and side lines of gutters where 8-in. stones may be used. They must have fairly smooth, even faces that will permit the construction of a gutter surface with a uniform contour.

108. Rubble Stones

Rubble stones shall be prepared from a hard, durable, tough stone, such as trap, granite, gneiss, etc., that has a fairly uniform fine grain, is sound, free from weathered or decomposed stone, shattered ends or structural defects, marked laminations, seams or cracks, and must be approved by the Engineer for the use intended.

When for use in a rubble gutter stone shall be not less than six (6) nor more than eight (8) inches in depth, not less than two (2) nor more than five (5) inches in width, and from six (6) to ten (10) inches in length. The top surface must be approximately flat, and so cut as to permit the construction of a gutter surface of the proper contour. When for use in rubble masonry unless otherwise specified the stone for the faces of the wall shall be not less than six (6) inches thick nor less than twelve (12) inches long. The width shall not be less than the thickness and the length shall not exceed three (3) times the thickness. Selected stones, rough squared, cut to the required pitch, shall be prepared for use at all angles and ends of walls.

109. Stone Block for Gutters

Stone block for gutters shall be prepared from a hard, tough rock such as trap, granite, gneiss, etc. In the selection of the stone all decomposed, weathered, soft, brittle or laminated stone will be excluded. The blocks should be of nearly the same degree of hardness and toughness. They shall be so cut that they will be practically rectangular in shape, be not less than six (6) nor more than eight (8) inches square on top, and from six (6) to eight (8) inches in depth. The blocks shall be so split and dressed as to form, when laid, close joints not exceeding one-half (½) inch in width on the top, and have a fairly smooth top and bottom surface.

110. Construction Brick

Brick for use in constructing manholes, catch-basins, etc., shall be new, whole building brick of a standard brand or make. They must be of a uniform commercial size.

The physical properties of construction brick shall comply with the requirements for "Hard Brick" as defined in A. S. T. M. standards, Serial Designation C21–20.

111. Masonry Stone

The stone used in the construction of stone masonry, such as retaining walls, headers, etc., shall be a hard, durable stone, that will easily permit of its being cut, chipped or chiseled into the required shape or form. Stone shall be of two grades, rough-dressed and hand-dressed. Rough-dressed stone shall be fairly rectangular in shape, have at least one smooth, even face, be not less than three (3) inches in thickness, nor less than eight (8) inches in width, and have a length greater than one-half the thickness of the wall in which the stone will be used. Hand-dressed stone will be hand dressed to nearly rectangular shape. The front face shall be smooth and even, free from objectionable depressions or projections, be rectangular in shape, have straight edges with square corners, and the other faces dressed nearly perpendicular to this face.

Hand-dressed stone shall be not less than eighteen (18) inches in length, six (6) inches in thickness, nor less than one (1) foot in width, and must be approved by the Engineer before being used.

Header stone shall be equal in length to the thickness of the wall in which it will be used.

112. Stone Curbing

Straight curbing shall be made from either granite or bluestone; circular curbing from granite only.

The granite used shall be a good grade of medium fine grain granite which has a uniform texture and distribution of its constituent minerals, is neither stratified nor laminated, and is free from seams, evidence of weathering, or disintegration.

The bluestone shall be a hard, durable stone that is free from such imperfections as soft or weathered spots, shattered layers, weathered bedding planes, or distinct lines of strati-

fication. It must be of sufficient hardness as to be serviceable, but not so hard as to be brittle or glassy.

All curbing shall be cut in lengths of not less than four (4) nor more than eight (8) feet, and be twenty (20) inches in depth unless a concrete footing is specified to be used, when the depth shall be sixteen (16) inches.

The top of all curbing shall be dressed to an even, smooth surface for full length, have straight, even edges, and a one-quarter (¼) inch bevel. The front faces shall be hand dressed full length for a depth of twelve (12) inches, and have a batter of one (1) inch from the top of the curb to the finished line of the gutter and be straight from this line to the bottom. The back face shall be hand dressed for a depth of three (3) inches. All dressed faces shall be free from depressions, projections or other defects, and hand dressed in a manner equal to four (4) cut stone finish. All curbing shall have square ends that will permit joints being made not more than one-quarter (¼) inch in width for full depth.

112A. Five-inch Curbing.

Five-inch curbing shall be five (5) inches in thickness on the top and not less than six (6) nor more than eight (8) inches in thickness on the bottom; other dimensions to be as above specified.

112B. Six-inch Curbing.

Six-inch curbing shall be six (6) inches in thickness on the top and not less than seven (7) nor more than eight (8) inches in thickness on the bottom; other dimensions to be as above specified.

112C. Eight-inch Curbing.

Eight-inch curbing shall be not less than eight (8) inches in thickness on the top nor less than nine (9) nor more than eleven (11) inches on the bottom; other dimensions to be as above specified.

112D. Circular Curbing.

Circular curbing shall be similarly cut and dressed in the same manner as straight curbing. It must be so cut as to conform accurately to the required radius. The ends shall be so cut as to permit of joints being made of not more than one-quarter (¼) inch in width for full depth.

113. Paving Blocks

113A. New Granite Paving Blocks.

New granite paving blocks shall be prepared from a granite of medium or fine-grained structure, showing an even distribution of the constituent minerals of uniform quality, structure and texture.

Physical Properties: The granite shall have a French coefficient of wear of not less than nine (9). The average of three determinations shall be used in reporting this test.

Dimensions: The blocks shall meet the following requirements:

Length on top	8 to 12 in.
Width on top	3½ to 4½ in.
Depth	4¾ to 5¼ in.

Dressing: The blocks shall be so dressed that the faces will be approximately rectangular in shape and the ends and sides sufficiently smooth to permit the blocks to be laid with joints not exceeding one-half (½) inch in width at the top and for a distance of one (1) inch down therefrom, and not exceed one (1) inch in width at any other part of the joint. The top surface of the block shall be so cut that there will be no depressions measuring more than three-eighths (⅜) inch in depth from a straight edge laid in any direction on the top of said block and parallel to the general surface thereof.

Care shall be exercised in handling the blocks so that the edges and corners shall not be chipped or broken. Blocks otherwise acceptable may be rejected on account of spalling.

Inspection: The Engineer or his authorized representative shall select at the work not less than three (3) blocks which fairly represent the actual shipment. These blocks shall be tested for the French coefficient of wear.

No samples shall include blocks that would be rejected by visual examination. The bedding plane shall be marked on at least two (2) of the blocks selected. All deliveries shall be subject to further inspection at the work prior to and during paving. Blocks

received at the work that are manufactured at a quarry other than the quarry or quarries stated in the certificate submitted by the Contractor at the time of bidding shall be rejected.

113B. Recut Granite Paving Blocks.

The recut granite paving blocks shall be made from the blocks in the street or roadway which is to be paved. Additional blocks required shall be either new granite blocks or made from other used granite blocks of the proper size and equal in quality to those in the pavement to be repaved.

Physical Properties: All recut blocks must show a French coefficient of wear equal to that specified herein for new granite paving blocks.

Dimensions—The blocks shall meet the following requirements:

Length on top	Not less than 6 in.
Width	3½ to 4½ in.
Depth	4¾ to 5¼ in.

Dressing: The blocks shall be so dressed that the faces will be approximately rectangular in shape and the ends and sides sufficiently smooth to permit the blocks to be laid with joints not exceeding one-half (½) inch in width at any part of the joint. Blocks less than six and one-half (6½) inches in length shall be reclipped. The head of the blocks shall be so cut that they shall have not more than three-eights (⅜) inch depression across the head measured from a straight edge held parallel to the general surface of the blocks.

Inspection: After the blocks have been recut they shall be carefully inspected. Undersized or irregular shaped blocks or those not complying with the above requirements shall be rejected and must be removed from the roadway.

113C. New Sandstone Paving Blocks.

Sandstone paving blocks shall consist of the best quality sandstone, free from quarry checks or cracks, and shall be quarried from fine grain live rock, showing a straight and even fracture. The material shall be of uniform quality and texture, free from seams, lines or clay, or other substances which, in the opinion of the Engineer, will be injurious to its use as paving blocks.

Physical Properties: All sandstone blocks must have a French coefficient of wear of not less than nine (9). The average of three (3) determinations shall be made in reporting this test.

Dimensions: The blocks shall meet the following requirements:

Length on top	8 to 12 in.
Width on top	3½ to 4½ in.
Depth	4¾ to 5¼ in.

Dressing: The blocks shall be dressed in the same manner as that specified for new granite paving blocks.

Inspection: The same method of inspection shall be used as that specified for the new granite paving blocks.

113D. Durax Paving Blocks.

Durax paving blocks shall be cut from a granite that complies with the requirements specified herein for new granite paving blocks.

Dimensions: Durax blocks shall have six (6) irregular, approximately square surfaces, the edges of which shall measure not less than two and three-quarter (2¾) inches, nor more than four (4) inches.

Dressing: The blocks shall be dressed so as to conform with the requirements specified for new granite blocks, except that the faces shall be square instead of rectangular.

Inspection: The same method of inspection shall be used for Durax blocks as that specified for new granite blocks.

113E. Vitrified Paving Brick.

All brick used for pavement or gutter surfaces shall be vitrified and prepared especially for paving purposes. They shall be pressed brick with lugs or wire-cut lug brick when the pavement is to be Portland cement grout filled, and wire-cut without lugs when the pavement is to be filled with a bituminous cement or bituminous mortar. Special forms shall be furnished when so ordered or required without extra compensation.

All brick shall be thoroughly annealed, tough and durable, regular in size and shape, and evenly burned. When broken, the brick shall show a dense, stonelike body free from lime, air pockets, cracks or marked laminations. Kiln marks shall not exceed three-sixteenth ($\frac{3}{16}$) inch, and the wearing surface shall show but slight kiln marks.

Representative samples of the brick shall meet the following requirements when subjected to the rattler test:

Average loss by abrasion on 3-in. wire-cut brick twenty-five (25) per cent.; maximum, twenty-seven (27) per cent.

Average loss by abrasion on $3\frac{1}{2}$-in. wire-cut brick, twenty-three (23) per cent; maximum, twenty-five (25) per cent.

An abrasion loss of one (1) per cent lower than that specified above will be required for repressed paving brick.

A maximum of three tests may be used as a basis for rejection.

The brick shall meet the following dimensions:

Either $8\frac{1}{2} \times 3 \times 4$ in., or $8\frac{1}{2} \times 3\frac{1}{2} \times 4$ in.

Variations among brick from a single plant shall not exceed the following limits:

	Inch
Variation in length	$\frac{1}{2}$
Variation in width	$\frac{1}{8}$
Variation in depth	$\frac{1}{8}$

If the edges of the brick are rounded, the radius shall not exceed three-sixteenth ($\frac{3}{16}$) inch.

The name or trade-mark of the manufacturer, if shown on the brick, shall be recessed and not raised.

The brick shall be subjected to inspection subsequent to delivery and during laying in order to cull out and reject upon variations from the general and dimensions clauses and upon the following grounds:

All brick which are broken through or chipped in such manner that neither wearing surface remains substantially intact, or in such manner that the lower or bearing surface is reduced in area by more than one-eighth ($\frac{1}{8}$).

All brick which are cracked to a depth greater than one-eight ($\frac{1}{8}$) inch on any surface, or which are cracked on the wearing surface.

All brick which are so offsized or mis-shaped, bent, twisted, or kiln marked that they will not form a proper surface or align properly with other brick.

All brick which are obviously too soft and too poorly vitrified to endure street wear.

113F. Asphalt Blocks.

These blocks shall be prepared from trap rock and a mineral filler of ground limestone or Portland cement bound together with an asphaltic cement. The trap rock shall be prepared by recrushing clean $\frac{3}{4}$-in. to $1\frac{1}{2}$-in. stone which is free from all weathered or decomposed material and quarry screenings. The product thus produced must all pass through a screen having circular openings one-quarter ($\frac{1}{4}$) inch in diameter, the stone therein shall be as near cubical as possible, and be so graded as to produce in the finished block, the mesh composition specified below. The mineral filler must fulfill the requirements given in Article 97; the asphalt cement, those for Grade NA.[5], as defined in Article 99A.

All blocks shall be uniform in texture and composition, straight, true to form, free from warp, wind, and broken corners or edges. The planes of the opposite faces and edges must be parallel. Each block shall be five (5) inches in width, twelve (12) inches in length, and two (2) inches in depth and any variation therefrom of over one-quarter ($\frac{1}{4}$) inch in length or one-eighth ($\frac{1}{8}$) inch in width or depth from these dimensions will cause the rejection of such blocks.

Anchor blocks shall, in addition to meeting the requirements specified hereinabove, have a strip of sheet iron one (1) inch wide so imbedded in the block that it is firmly held in place, does not project less than three-eighths ($\frac{3}{8}$) inch or over one-half ($\frac{1}{2}$) inch below the surface of the face of the block, is elliptical in shape, the major axis of which is not less than nine (9) inches or over ten (10) inches and the minor axis not less than two and one-half ($2\frac{1}{2}$) inches or over three (3) inches.

All blocks must have a specific gravity at 15.5°C., of not less than 2.40 and be so prepared that they will comply in all respects to the following additional requirements.

COMPOSITION

Size of screen and sieves		Minimum, per cent	Maximum, per cent
Passing	Retained on		
.....	¼-in. screen	....	0.0
¼-in. screen	20-mesh	35.0	50.0
20-mesh	100-mesh	15.0	30.0
100-mesh	.....	26.0	36.0
Bitumen content	.....	6.5	8.0

After having been dried for twenty-four (24) hours at a temperature of 150°F., the blocks shall not absorb more than one (1) per cent of water, based on the weight after drying, when immersed in water for seven (7) days.

The average penetration of the block under the punch test shall not exceed 0.25 in. at 100°F., and 1.00 in. at 115°F.

Blocks which have the corners or edges broken off of one end only and will pass the other requirements giving hereinabove, may be used for half blocks adjacent to curb, for breaking courses, and in making closures.

In addition to the above requirements, the block must be prepared by a manufacturer or producer who is experienced in the preparation of such blocks. Before approval by the Engineer of any blocks of this type, the manufacturer or producer thereof must submit a statement giving the locations of two or more pavements that are five (5) years or more old, have given good service during this time, do not show evidence of an unnatural wear or deterioration, and were constructed of paving blocks of the type herein specified.

Each consignment or carload shall be sampled in such a manner that each sample represents about ten thousand (10,000) blocks. The blocks selected for the samples shall be taken at random from the shipment and shall represent the average quality of blocks contained in the consignment. In case the blocks fail to pass the tests herein specified, a check analysis shall be made on another sample similarly selected. If the check sample passes the requirements above specified, the shipment or consignment shall be accepted, otherwise rejected, unless the Engineer shall agree to resample the consignment.

113G. WOODEN BLOCKS.

All wooden blocks used for paving purposes shall be creosoted in the manner designed below, and comply with the other requirements given.

Quality of Wood for Blocks: The lumber to be used in manufacturing blocks shall be Southern yellow pine, Norway pine, Douglas fir, tamarack, black gum or hemlock, but only one kind shall be used on any one section of pavement.

The blocks shall be sound and shall be well manufactured, square-butted, square edged, free from unsound, loose or hollow knots, knot holes, worm holes, and other defects such as shakes, checks, etc., which would be injurious to the blocks.

The number of annual rings in the one (1) inch measured radially, which begins two (2) inches from the pith of the block, shall not be less than six (6), provided, however, that blocks containing between five (5) and six (6) rings in this inch will be accepted if they contain thirty-three and one-third (33⅓) per cent or more of summer wood. In case the block does not contain the pith, the one (1) inch to be used shall begin one (1) inch from the ring which has the shortest radius. When being treated the blocks in each charge shall contain an average of at least seventy (70) per cent of heart-wood. No one block shall be accepted that contains less than fifty (50) per cent of heart-wood.

Size of Block: Blocks shall be from five (5) to ten (10) inches in length, but shall have an average length of twice the depth; they may be from three (3) to four (4) inches in width, and three (3), three and one-half (3½) or four (4) inches in depth, as specified. Only

block of a single width shall be used in a section of pavement. A variation of one-sixteenth ($\frac{1}{16}$) of an inch shall be allowed in the depth, and one-eighth ($\frac{1}{8}$) inch in the width of the block.

Properties of Preservatives: The preservative to be used in manufacturing of block shall be a coal tar distillate or a coal tar paving oil, complying with the requirements given therefor. The preservatives used shall be designated by the Engineer, but only one preservative shall be used on any one contract.

Inspection of Preservative: The manufacturer of the blocks shall permit complete sampling at all times and places, and shall furnish, if required, satisfactory proof of the origin of the preservative. Samples of the preservative, taken from the treating tank during treatment, at no time shall show an accumulation of more than two (2) per cent of sawdust, dirt, or other foreign materials. Due allowance shall be made for such accumulation of foreign materials by injecting an additional quantity of preservative into the blocks.

Treatment of Blocks: The blocks shall be treated with the preservative under pressure so that they shall contain not less than sixteen (16) pounds per cubic foot, and at no time shall be subjected to a temperature of more than two hundred and forty (240) degrees Fahrenheit. They shall show satisfactory penetration of the preservative after treatment. All blocks which have become warped, checked or otherwise injured in the process of treatment will be rejected.

Inspection of Blocks: The blocks will be subjected to inspection before, during and after treatment and may be reinspected at any time. The plant shall be equipped with gages and appliances necessary for suitable inspection and every facility for this inspection shall be afforded.

Handling of Blocks: The blocks at all times shall be kept clean, piled neatly and shall be handled carefully, as blocks otherwise acceptable may be rejected if they become coated with dirt.

114. Pipes

All pipe of any given type, grade or size must be uniform in appearance, composition and texture. The smallest inside diameter shall be the governing size. Unless otherwise specified, all lengths must be straight, true to form, with circular cross-sections and free from cracks, holes, ragged chips or broken ends. No culls, second grade, used or second-hand, injured or defective pipe, shall be used, or other grades or sizes substituted for those specified. No pipe shall be used until approved by the Engineer. Whenever possible, the manufacturer should have consignments inspected and approved before shipment.

114A. Drain Tile.

The pipe used for drain tile shall be either vitrified tile or machine-made concrete pipe, unless otherwise shown on plans.

Vitrified pipe shall be of the best grade, first quality, salt-glazed pipe of the hub and spigot type. The grazing shall extend uniformly over both the exterior and interior surfaces. It shall be uniformly and thoroughly burned, free from blisters, cracks, or other defects that will injure it for the purpose intended. The dry pipe must give a clear metallic ring when tapped. It shall be furnished in lengths of not less than twenty-four (24) inches. The inside diameter shall be the determining size. Unless otherwise specified, all lengths must be straight. When required, curved or special forms of pipe shall be furnished.

Concrete drain pipe shall be made of the same materials and in the manner specified for machine made reinforced concrete pipe, given below, with the exception that no reinforcing metal is required and the ultimate strength of pipe shall be 1,000 D. The dimensions for this kind of pipe shall conform to the A. S. T. M. requirements, Serial Designation C14–21.

114B. Cast-iron Pipe.

All cast-iron pipe shall be of the hub ahd spigot style. It shall be manufactured in the lengths specified. When no length is designated, it shall be manufactured, in lengths not less than three (3) feet nor more than twelve (12) feet. Unless otherwise specified, each length shall have square ends, be straight in the direction of the cylinder and the inner and outer surfaces shall be concentric and true circles in cross-section. All pipe shall be

smooth, free from scales, lumps, blisters, cracks, broken ends or other defects considered injurious for the use intended. Small sand- or blow-holes will not be considered defects. Each joint shall have the maker's initials cast upon it in raised letters.

All cast-iron pipe shall be made from first quality cast iron which is free from clinker iron or other inferior iron. It must produce a sound, tough, durable casting, having a uniform, even grain that is soft enough to admit satisfactorily of drilling and cutting.

Either cast-iron water pipe, Grade A, or cast-iron culvert pipe will be accepted provided it complies with the requirements given above and its weight per lineal foot is not less than that given below for the different sizes.

Nominal inside diameter, inches	Thickness, inches	Weight per lineal foot, pound
4	0.42	20.0
6	0.44	30.8
8	0.46	42.9
10	0.50	57.1
12	0.54	72.5
14	0.57	89.6
16	0.60	108.3
18	0.64	129.2
20	0.67	150.0
24	0.76	204.2
30	0.88	291.7
36	0.99	391.7

No pipe will be accepted, the weight of which shall be five (5) per cent less than the weights herein specified.

Each section of cast-iron pipe shall be coated inside and outside with coal-tar pitch varnish to which sufficient linseed oil has been added to make a smooth coat, tough and tenacious when cold, with no tendency to scale off.

114C. Corrugated Sheet Iron or Steel.

Size and Shape: Each joint shall have square ends, be circular in form and of the size and length indicated on plans. When no particular length of joint is indicated, the pipe shall be shipped in standard lengths of the required size. The inlet and outlet ends shall be reinforced by a round rod not less than one-half (½) inch in diameter. Sufficient metal shall be lapped over this rod to cover it completely. Each joint shall be firmly and neatly riveted together, the rivets being spaced not over three (3) inches apart in longitudinal seams, nor more than eight (8) inches apart in circumferential seams. The metal shall be lapped not less than one and one-half (1½) inches in longitudinal seams nor less than one (1) corrugation in circumferential seams.

Composition of Materials Used: All corrugated pipe shall be manufactured from galvanized sheets of iron or steel that were prepared from either a pure iron or a copper-bearing pure iron steel. These sheets must be uniform in thickness, and free from blisters, scales, or other defects which will injure them for galvanizing. All rivets, reinforcing rods and couplings or connecting bands shall be made from the same grade metal as the body of the pipe.

Pure iron shall be so refined that it shall have an iron content of not less than ninety-nine and seventy-nine hundredths (99.79) per cent, copper-bearing pure iron, not less than 99.75 per cent and not less than 0.20 per cent of copper. Copper steel shall be so prepared that it shall contain not less than three-tenths (0.3) of one (1) per cent of copper nor more than fifteen hundredths (0.15) per cent of Carbon, five hundredths (0.05) per cent of Sulphur, four hundredths (0.04) per cent Phosphorus, and from thirty hundredths (0.30) to forty-five hundredths (0.45) per cent Manganese.

Galvanizing: All sheet metal used in the manufacture of corrugated pipe shall be galvanized on both sides by the hot dipping process. Each square foot of uncorrugated sheet

shall contain not less than two (2) ounces of spelter, evenly distributed over both surfaces. The zinc coating must be uniform in thickness, completely cover both sides, firmly adhere thereto, and be free from imperfections of any kind, and show no signs of cracking or blistering. All rivets, reinforcing rods, and couplings or connecting bands shall be galvanized in the same manner as the sheets.

Corrugation: The corrugations of any one given size of pipe shall be uniform but must not be less than three-eighths (3/8) inch in depth, nor more than three (3) inches from center to center.

Gages of Sheets Required: Corrugated metal pipe shall be made of sheets of the following thickness (U. S. Standard Gage Measure):

Diameter	Gage
Pipe from 12 to 20 in. shall not be lighter than	16
Pipe from 24 to 30 in. shall not be lighter than	15
Pipe from 36 to 42 in. shall not be lighter than	14
Pipe from 48 to 60 in. shall not be lighter than	12

114D. Reinforced Concrete Pipe.

Type of Pipe: Reinforced concrete pipe may be either cast or machine made. Each type shall conform in size, shape and reinforcement to the standards as shown in the table forming a part in these specifications. The letter C or M shall be plainly impressed upon the outside surface of each length of pipe to designate whether it is cast or machine-made respectively. Each length of pipe shall also be clearly marked with the date of manufacture and the name or trade mark of the manufacturer.

Shape: All concrete pipe 12 in. or over in diameter shall be reinforced as herein specified and be of the bell and spigot type unless some other type is specified or shown on the plan. Each section shall have square ends, be circular or elliptical in cross-section, unless otherwise specified, and have walls of uniform thickness throughout except the bell end, which shall have a thickness of not less than three-fourths (3/4) of the wall thickness at a point 1/4 in. from the end of the bell.

Size: It shall be cast in sections, the length of which shall be as herein specified or shown on plans. When no particular length is specified, the pipes shall be manufactured in standard lengths of not less than four (4) feet, nor more than six (6) feet. The smallest inside diameter shall govern in deciding the sizes of any given pipe.

Joints: The bell end shall be so constructed that the spigot end will enter to full depth. The distance the spigot end must enter freely shall be as follows: 12 to 18-in. pipes not less than two and one-half (2 1/2) inches; 18 to 30-in. pipe, not less than three (3) inches; and 30 to 72-in. pipe, not less than three and one-half (3 1/2) inches.

Finish: The surface of all pipe, both interior and exterior shall be smooth and even, of uniform texture, free from surface checks, cracks, blisters, fractures, laminations, lean and porous spots. The pipe shall be true to dimensions intended in the design with a permissible variation from the true form of not more than 1 1/2 per cent. The shell of the pipe may be thicker than called for in the designs, but it shall not be less than the designated shell thickness by more than 5 per cent.

Composition: Concrete pipe shall be prepared from a concrete mortar having the following composition:

Portland cement	1 part by volume
Fine aggregate	1 to 2 parts by volume
Coarse aggregate	3 parts by volume

and sufficient reinforcing metal to meet the requirements given below.

Materials: The Portland cement shall comply with the requirements given in Article 96. The fine aggregate shall be concrete sand, complying with the requirements given in Article 95-B. The coarse aggregate shall be dustless screenings prepared from trap rock, dolomite or pea gravel as defined in Articles 92 and 94 respectively.

The reinforcing metal shall be woven wire mesh, expanded metal, rods, hoops, or spirals manufactured from billet steel which complies with the requirements specified therefor by the American Society for Testing Materials, Serial Designation A 15–14. It must be free from grease, dirt, rust, or any foreign material that will prevent the concrete from properly adhering thereto.

Preparation: Concrete pipe shall be prepared from the materials above specified. Each length shall be cast in a single operation. The moulds must be properly assembled, cleaned and oiled when so ordered before any concrete mortar is placed therein. The reinforcing metal must be so held in the required position that it will not be displaced during manufacture of the pipe. For cast pipe the forms shall not be removed until the concrete is at least twelve (12) hours old, and after removal unless steam cured, the pipe must be covered and be kept wet at least ten (10) days. Pipe manufactured when the atmospheric temperature may drop below 35°F. must be so protected that the concrete therein will not at any time have a temperature below 35°F., until the concrete is at least seven (7) days old. Pipe shall not be shipped for use that is less than fourteen (14) days old.

Reinforcement: All pipe shall be reinforced as herein specified. Pipe under thirty (30) inches in diameter shall have a single line of reinforcement, thirty (30) inches and above, two lines of reinforcements as shown in the table below or an approved method of reinforcement developing equivalent strength.

Single lines of reinforcement shall be placed at equal distances from the inside and outside surfaces of the pipe.

Double lines of reinforcement shall be placed parallel to each other and one (1) inch from the inside and outside surface walls of the pipe, other requirements to be as above defined for single line reinforcements.

Longitudinal reinforcement shall extend full length of each section and into the bell, and shall be wired or otherwise securely fastened to the body and bell reinforcement.

Circular reinforcement shall extend completely around the pipe and have adjacent ends lap not less than forty (40) diameters of the circular reinforcement and be firmly fastened together.

The thickness of the pipe walls and total cross-sectional area of circular and longitudinal reinforcement for the different sizes of the pipe shall be not less than those shown in the table given below:

Diameter of pipe, inches	Cast pipe		Machine-made pipe		Longitudinal reinforcing	
	Shell thickness, inches	Minimum area of circular reinforcing per ft. of pipe	Shell thickness, inches	Minimum area of circular reinforcing per ft. of pipe	Minimum number of long	Minimum total area long
12	2	0.070	1½	0.093	4	0.196
15	2¼	0.096	1¾	0.123	4	0.196
18	2½	0.123	2	0.160	4	0.196
24	3	0.180	2½	0.220	4	0.196
30	3½	2 × 0.167	3	2 × 0.210	8	0.392
36	4	2 × 0.200	3	2 × 0.300	8	0.614
42	4½	2 × 0.230	3½	2 × 0.320	8	0.614
48	5	2 × 0.265	4	2 × 0.350	8	1.200
54	5½	2 × 0.300	4½	2 × 0.390	12	1.326
60	6	2 × 0.330	5	2 × 0.410	12	1.326

Strength: When supported at the bottom upon a knife edge one (1) inch in width, or upon two rounded bearings centered two (2) inches apart, in such manner that an even bearing is provided throughout the whole length, exclusive of the bell, and load is applied at the crown through a similar knife edge, all pipe twenty-four (24) inches in diameter and greater shall withstand, without the appearance of a visible crack extending through the entire length of the pipe, a load of 1,000 D lb. per lineal foot of laying length; all pipe of a diameter less than 24 in. when tested in a similar manner shall withstand a load of

1,330 lb., as specified for larger size pipe. When tested to destruction, all pipe of twenty-four (24) inches diameter and greater shall show an ultimate strength of not less than 1,500 D lb. per lineal foot of laying length; all pipe of a diameter less than twenty-four (24) inches shall, in a similar manner, show an ultimate strength of not less than 2,000 D lb. per lineal foot of laying length. In the above expression of load D is the inside diameter of the pipe in feet.

Absorption: The maximum average absorption as obtained by the A. S. T. M. standard boiling test shall not exceed eight (8) per cent by weight.

Testing: Each manufacturer furnishing pipe under these specifications shall be fully equipped to carry out the tests herein designated. Upon the demand of the Department and under its supervision, the manufacturer shall perform such number of tests as the Department may deem necessary to establish the quality of the pipe offered for its use. Failure of any size of pipe to meet the test requirements shall be sufficient cause for rejection of all pipes of that size, which the test specimen represents.

Inspection: All pipes shall be subject to inspection at the factory, or point of delivery, by a competent inspector employed by the Department. The purposes of the inspection shall be to cull and reject pipes which, independent of the physical tests herein specified, fail to meet the requirements of these specifications and rejection through inspection may be made on account of any of the following:

(*a*) Porous spots on either inside or outside surface of pipe having an area of more than ten (10) square inches and a depth of more than one-half inch.

(*b*) Pipe which have been patched to repair porous spots, cracks or other defects.

(*c*) Variations in any dimension exceeding the permissible variations.

(*d*) Fractures or cracks passing through the body or bell, except that a single crack at either end of pipe not exceeding three inches in length or a single fracture in the bell not exceeding 2 in. in depth nor extending more than 10 per cent around the circumference of the bell will not be considered cause for rejection.

(*e*) Failure to give a clear ringing sound when tapped with a light hammer.

(*f*) Exposure of the reinforcement when such exposure would indicate that the reinforcement was misplaced.

(*g*) In machine-made pipe the entire absence from the exterior surface of a pipe of the characteristic water marks due to suction, caused by the removal of the outer form, shall be considered proof of an insufficient quantity of mixing water and shall be sufficient cause for rejection of such pipe.

115. Reinforcing Metal

All reinforcing metal shall be made from open-hearth or Bessemer steel, complying with the A. S. T. M. Standard Requirements of tentative standards for the type of steel from which the reinforcing metal is required to be made.

When any special design, shape or form of reinforcing metal is specified to be used, the same shall be used in the manner and in the quantity required. All reinforcement shall be placed as shown or as otherwise ordered by the Engineer. It must be free from rust, paints, oils, grease, or other foreign materials that will prevent the proper bond being secured between the concrete and the metal. All reinforcement must be straight unless curved or special shapes are required. When so required, they must have the designated shape when used.

When reinforcing bars or rods have to be spliced, the lap shall be not less than forty (40) diameters for deformed rods, or fifty (50) diameters for plain rods. The lapped ends shall be firmly clamped together or otherwise securely fastened in a manner satisfactory to the Engineer. All bars or rods shall be firmly and securely fastened together in a satisfactory manner at all intersections. At intersections the members in reinforcing fabric shall be welded or otherwise securely fastened.

116. Structural Steel

Structural steel shall be prepared from a steel that complies with the requirements given in Volume 16, Part 1 of the A. S. T. M., Pages 99 and 111 to 113. A coupon giving the analysis of the Melt Number from which the steel forms or structures were made shall be furnished with each shipment.

Whenever any special forms or shapes are specified to be used, the steel shall be made to conform to such shapes and dimensions. The methods used in manufacturing the steel into the forms required shall be such that the steel is not injured thereby. All shearing and chipping shall be neatly and accurately done, and all portions of the steel which will be exposed to view must be neatly finished. All holes must be neatly punched and riveting and bolting performed in a workmanlike manner. Undersized holes shall be reamed to size. All pins and rivets must be full size and fit accurately at normal temperature.

All structural steel must be protected from the weather and have clean surfaces before being worked into the proper shapes or forms. When structures are required to be painted before shipment, the surfaces must be cleaned and given a coat of an approved paint.

117. Miscellaneous Iron and Steel

All cast iron, malleable iron, or cast-steel castings shall be prepared in the manner and from a metal which complies with the A. S. T. M. requirements as defined in the 1918 Year Book, Pages 406, 403 and 220 respectively.

When any special size, shape or form is specified to be used, the casting must comply with these dimensions. All castings must have the weight and thickness of metal as specified or shown on plans. They must be neatly finished, free from fins, broken edges, blow-holes, cracked sections or warped surfaces. They must be properly protected during shipment and painted when so specified.

118. Guard Rails

Guard rails shall be made either of wood or galvanized pipe as specified. The dimensions or sizes of materials to be used therefor shall be as specified. When no definite size or character of material as specified for a given type of guard rail, the material furnished shall comply with the requirements given below for such materials.

118A. Wooden Guard Rails.

The lumber used in all wooden guard rails shall be well seasoned, straight-grained, sound, surfaced on all sides and be free from shattered or cracked ends, barked edges, loose or unsound knots and reasonably free from other knots.

The wooden rails shall be made from long leaf yellow pine, chestnut or oak. The top rails or caps shall be 2-in. plank, eight (8) inches wide, sixteen (16) feet long. The bottom rail shall be 2-in. plank ten (10) inches wide, and sixteen (16) feet long. All rail plank must have square ends for the full width of the plank. Rails and caps shall have their joints on alternate posts.

Posts shall be made from chestnut, oak, locust, white or red cedar. They shall not be less than seven (7) feet in length, six (6) inches square, have the top ends cut to the bevel required, the lower end off square, and the lower four (4) feet treated. The treatment shall consist of immersing the posts in a bath of hot tar. The tar used for this purpose shall be Grade A or U^2, as defined in Articles 100A and 100B. The tar shall be heated between 225 and 275°F., and kept at this temperature during the treatment of the posts.

The posts shall be placed in a vertical position in the hot tar for not less than thirty (30) minutes, or as much longer as is needed to heat the lower four (4) feet of the posts to the same temperature as the tar. Immediately upon removing from the hot tar, it shall be immersed in a bath of cold tar of the same grade until cooled to normal temperature. The portion of the posts treated shall be slightly in excess of the depth that the posts will be placed in the ground, but in no case shall the treatment extend more than six (6) inches above the ground.

118B. Galvanized Pipe Rails.

All pipe shall be made from the best grade of galvanized wrought-iron pipe that is equal in every respect to the best grade of "Byers' Wrought-iron Galvanized Pipe." All such pipe must have an even, smooth surface, be full weight and thickness, well threaded and free from rust or cracks. All fittings used in pipe guard railing, shall be galvanized and made from malleable iron that is free from flaws, cracks, etc. They shall be neatly threaded or bored to the required size needed for the proper installation of the pipe.

119. Timber and Lumber

General.

All timber or lumber shall be well seasoned, straight grained, sound, free from loose knots, worm holes, shattered or cracked ends, barked edges, or other defects that impair its strength or durability for the use intended. It must be cut or sawed to the specified size and dimensions, and when painting is required, must be surfaced on all faces to be painted It must be of sufficient length to give square ends for full width of the length specified.

When a special kind or grade of timber or lumber is specified, this kind or grade must be furnished. When no kind or grade is specified, the wood may be white oak, chestnut, long leaf yellow pine. Timber for use as piling must withstand the specified driving without spreading or excess brooming of the head. It must be not less than six (6) inches in diameter at the point or ten (10) inches at the butt. It must have a uniform taper from butt to tip, have the bark removed, be free from short bends, and a straight line from the center of the butt to the center of the tip, shall lie wholly within the body of the pile. All knots or blemishes must be trimmed off close and even with the body of the pile. The lower ends shall be cut square or tapered as may be directed by the Engineer.

Timber or lumber to be creosoted, unless otherwise specified, shall comply with the requirements given above and shall be long leaf yellow pine. It must be treated with the creosote oil described in paragraph 102, and the treatment so performed that the wood will absorb not less than twelve (12) pounds of oil per cubic foot for lumber having a minimum cross-section not over four (4) inches, or eight (8) pounds per cubic foot for lumber having a minimum cross-section of not less than six (6) inches.

120. Paints

120A. General.

All paints shall be shipped in strong, substantial containers, plainly marked with the name and weight of paint content, and name and address of the manufacturer. When so requested, samples and analysis of all pigments, oils, thinners, or driers used, or paints furnished shall be supplied by the manufacturer within ten (10) days after request is made therefor.

Paints shall consist of pigments of the required fineness and composition, ground to the desired consistency in raw or boiled linseed oil, to which shall be added additional oil, and a thinner, or a drier, or both. All pigments, oils, thinners, and driers used shall be of the best quality, free from adulterants of any kind, and shall comply with the requirements given below for these materials.

120B. Paint Paste.

All paint paste shall consist of the specified pigment or pigments ground in linseed oil to the required consistency. The paste must be so prepared that it is uniform in composition and consistency, will not cake or segregate in the retainers, and will easily break up in oil to form a smooth, uniform paint of brushing consistency which will not run nor sag. The color, hiding power, and weight per gallon when specified shall be the same or equal to the approved sample.

120C. Ready Mixed Paints.

To prepare a paint so that it will have the required consistency and curing properties for the use intended, the paste shall be mixed with sufficient linseed oil, turpentine, and drier to produce a paint having these properties. Unless otherwise specified, the exact quantity of linseed oil, turpentine, and drier required for this purpose shall be determined by the Engineer.

120D. Raw and Boiled Linseed Oil.

Raw linseed oil must be strictly pure, well settled linseed oil, perfectly clear and not show any sediment or loss of more than two-tenths (.2) per cent when heated for one-half (½) hour at temperature between 105 and 130°C.

Boiled linseed oil shall be made by heating the raw linseed oil to at least 350°F., with oxides of lead and manganese for a sufficient length of time to secure the proper combination

of the constituents. After this it shall be properly clarified by settling or other suitable treatment.

The oil shall be rejected if it shows the presence of any foreign matter, other than lead or manganese or compounds of these metals.

Raw and boiled linseed oil shall conform to the following requirements:

Material	Raw linseed oil		Boiled linseed oil	
Tests	Min.	Max.	Min.	Max.
1. Specific gravity at 15.5°C./15.5°C.	0.932	0.936	0.937	0.945
2. Acid number	.....	6.00	.....	8.00
3. Saponification number	189	195	189	195
4. Unsaponificable matter, per cent	.....	1.50	.....	1.50
5. Refractive index at 25°C	1.479	1.4805	1.479	1.484
6. Iodine number (Hanus)	180	.....	178	
7. Ash, per cent	.....	.....	0.2	0.7
8. Manganese, per cent	.....	.....	0.03	
9. Calcium, per cent	.....	.....	.....	0.3
10. Lead, per cent	.....	.....	0.1	

120E. Turpentine or Thinner.

Turpentine shall be the distillate commonly known as "Gum Turpentine" or "Spirits Turpentine" which is distilled from pine oleoresins or the product secured from resinous wood by extraction with volatile solvents, by steam or by destructive distillation. Either or both of these two products; gum spirits or wood turpentine, shall be furnished for use when so specified.

The turpentine shall be clear and free from suspended matter and water.

The color shall be "Standard" or better.

The specific gravity shall not be less than 0.862 nor more than 0.872 at 15.5°C.

The refractive index at 15.5°C. shall not be less than 1.468 nor more than 1.478.

The initial boiling point shall not be less than 150 nor more than 160°C.

Ninety (90) per cent of the turpentine shall distill below 170°C.

The polymerization residue shall not exceed two (2) per cent, and its refractive index at 15.5°C. shall not be less than 1.500.

120F. Drier.

The drier shall be composed of lead and manganese oxides in combination with pure linseed oil and solvent. It must be free from adulterants, sediment and suspended matter. It shall not flash below 95°F. in an open tester or 72°F. in a closed Abel tester.

120G. Pure White Lead.

Dry Pigment: The pigment shall be a pure basic carbonate of lead of the formula $2PbCO_3PbOH_2$, containing sixty-five (65) to seventy-five (75) per cent of lead carbonate, and not more than two (2) per cent of total impurities, including moisture. It shall be ground to such fineness that it will all pass a 200-mesh sieve and contain no more than two (2) per cent material retained on a 325-mesh sieve.

Paste: The paste shall be the dry pigment ground in oil in the manner specified above.

It shall consist of:

	Percentages	
	Minimum	Maximum
Pigment	90	92.0
Linseed oil	8	10.0
Moisture and other volatile matter	..	0.7
Coarse particles and "skins" (total residue retained on a 325-mesh sieve based on pigment)	..	2.0

Ready Mixed Paint: The ready mixed paint shall be prepared from the paste in the manner specified above.

120H. Pure Zinc Oxide Paint.

Dry Pigment: The dry pigment shall consist of pure oxide of zinc which shall contain not less than ninety-eight (98) per cent of zinc oxide nor more than two-tenths (0.2) per cent of sulphur or two (2) per cent of total impurities including moisture. The pigment shall be so ground that it will all pass a 200-mesh sieve.

Paste: The paste shall be the dry pigment ground in oil as above specified. It shall consist of:

	Percentages	
	Minimum	Maximum
Pigment	82	86.0
Linseed oil	14	18.0
Coarse particles and "skins" (total residue left on a 200-mesh sieve, based on pigment)	..	0.5
Moisture and other volatile matter	..	0.5

Ready Mixed Paint: The ready mixed paint shall be prepared from the paste in the manner specified above.

120I. Red Lead.

Dry Pigment: The dry pigment shall consist entirely of the oxides of lead which shall contain from eighty-five (85) to ninety-five (95) per cent of PB_3O_4, not more than one (1) per cent of total impurities and shall be so ground that not more than three-tenths (0.3) per cent is retained on a 200-mesh sieve.

Paste: The paste shall be the pigment ground in oil as above specified. It shall consist of:

	Percentages	
	Minimum	Maximum
Pigment	92	94.0
Linseed oil	6	8.0
Moisture and other volatile matter	..	0.5
Coarse particles and "skins" (total residue left on a 200-mesh sieve)	..	0.5

Ready Mixed Paint: The ready mixed paint shall be prepared from the paste in the manner specified above.

The resulting paint, when mixed in the proportions given below and brushed on a smooth, vertical, iron surface, shall dry hard and elastic without running, streaking, or sagging.

Red lead paste	20 lb.
Raw linseed oil	4½ pt.
Turpentine	2 gills
Liquid drier	2 gills

120J. Leaded Zinc Oxide.

Dry Pigment: The dry pigment shall be a pure zinc oxide and a normal or basic lead sulphate. The pigment shall be so ground that it will all pass a 200-mesh sieve and the zinc oxide shall not contain more than one (1) per cent of soluble salts nor more than one and five-tenths (1.5) per cent of total impurities including moisture.

This type of paint shall be divided into two brands, "High Leaded" and "Low Leaded." The high leaded paint shall contain not less than sixty (60) per cent of zinc oxide and the low leaded paint not less than ninety-three (93) per cent of zinc oxide, the remaining pigment in each case to be a normal or basic lead sulphate.

Paste: The paste shall be the dry pigment ground in oil as above specified. It shall consist of:

	Percentages	
	Minimum	Maximum
Pigment	....	88.0
Linseed oil	12.0	
Moisture and other volatile matter	....	0.5
Coarse particles and "skins" (total residue left on a 200-mesh sieve based on pigment)	....	0.5

Ready Mixed Paint: The ready mixed paint shall be prepared from the paste in the manner specified above.

120K. White Basic Sulphide.

Dry Pigment: The pigment shall be the sublimated product prepared from lead sulphide ores. The pigment shall be so ground that it will all pass a 200-mesh sieve, contain not

more than five-tenths (0.5) per cent of material retained on a 325-mesh sieve and have the following composition:

Lead oxide	eleven (11) to eighteen (18) per cent
Zinc oxide	not more than nine (9) per cent
Total impurities, including moisture	not more than one (1) per cent

The remainder shall be lead sulphide.

Paste: The paste shall be the pigment ground in oil as above specified. It shall consist of:

	Percentages	
	Minimum	Maximum
Pigment	89	91.0
Linseed oil	9	11.0
Moisture and other volatile matter	..	0.7
Coarse particles and "skins" (total residue retained on a 325-mesh sieve, based on pigment)	..	0.5

Ready Mixed Paint: The ready mixed paint shall be prepared from the paste in the manner specified above.

120L. Tinted Paint with White Base.

Dry Pigment: The ingredients used in preparing this pigment shall comply with the requirements given above for said ingredients. The pigments shall be composed of:

	Percentages	
	Minimum	Maximum
White lead (basic carbonate, basic sulphate, or a mixture thereof)	45	70
Zinc oxide (ZnO)	30	55
Silica, magnesium silicate, aluminum silicate, barium sulphate, pure tinting colors, or any mixture thereof	0	15

In no case shall the sum of the basic lead carbonate, basic lead sulphate, and zinc oxide be less than eighty-five (85) per cent of the mixture. The lead and zinc pigments may be introduced in the form of any mixture prepared from basic carbonate white lead, basic sulphate white lead, zinc oxide, or leaded zinc, provided the above requirements as to composition are met.

Liquid: The liquid in semi-paste paint shall be entirely pure, raw or refined linseed oil; in ready mixed paint it shall contain not less than ninety (90) per cent pure raw linseed oil, the balance to be combined drier and thinner. The thinner shall be turpentine, volatile mineral spirits, or a mixture thereof.

Semi-paste: The paste shall be the pigment ground in oil as above specified. It shall mix readily in all proportions without curdling with linseed oil, turpentine, or volatile mineral spirits, or any combination of these substances. The color, hiding power, and

weight per gallon when specified, shall be not less than that of the approved sample. The paste shall consist of:

	Percentages	
	Minimum	Maximum
Pigment	73	77.0
Linseed oil	23	27.0
Moisture and other volatile matter	..	0.7
Coarse particles and "skins" (total residue on a 200-mesh sieve based on pigment)	..	0.5

Ready Mixed Paint: The ready mixed paint shall be prepared from the paste in the manner specified above. The weight per gallon shall be not less than fifteen and three-quarter (15¾) pounds. The paint shall consist of:

	Percentages	
	Minimum	Maximum
Pigment	62	66.0
Liquid (containing at least 90 per cent linseed oil)	34	38.0
Water	..	0.5
Coarse particles and "skins" (total residue retained on a 200-mesh sieve, based on pigment)	..	0.5

120M. GRAPHITE.

Dry Pigment: The dry pigment shall be a pure natural flake graphite and silicate rock to which may be added a small percentage of carbon black, iron oxide, or other oxides needed to secure a desired tint or color. The pigment shall be so ground that it will all pass a 200-mesh sieve, and contain not more than ten (10) per cent of material retained on a 325-mesh sieve. The prepared pigment must contain not less than forty-five (45) per cent of natural graphite.

Paste: The paste shall be the pigment ground in oil as above specified. It shall consist of:

	Percentages	
	Minimum	Maximum
Pigment	62	66.0
Linseed oil	34	38.0
Moisture and other volatile matter	..	0.80
Coarse particles and "skins" (total per cent on a 325-mesh sieve, based on the pigment)	3	6.0

Ready Mixed Paint: The ready mixed paint shall be prepared from the paste in the manner specified above.

The resulting paint when mixed in the proportions given below, and brushed on a smooth, vertical iron surface shall dry hard and elastic without running, streaking, or sagging. It shall consist of:

	Percentages	
	Minimum	Maximum
Pigment	30	35
Boiled linseed oil	65	70
Japan drier	5	6
Turpentine and volatile matter	3	6

APPENDIX B

RECONNAISSANCE REPORT AND ESTIMATE WOODVILLE—BRISTOL SPRINGS—CHESHIRE

F. A. PROJECT NO. 184

Made for _____, Division Eng., Rochester, N. Y.,

By W. G. Harger, Locating Eng.

Dec., 1922

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PART I. GENERAL NON-TECHNICAL REPORT

Necessity for Report:

The following report is necessary as the Federal Bureau has refused to approve the plans previously submitted until they are furnished with additional data in regard to the possibilities and cost of 7 per cent maximum grades in place of the 10 per cent grades used. This report provides the engineering information on which a reasonable general decision can be made by the Commissioner and Federal Engineers as to whether the old plans will be approved or new plans prepared. The data is based on a Stadia Reconnaissance Survey and the estimate is probably correct to within 15 per cent of final plan amounts, which is sufficiently close for the purpose desired.

Construction Cost and Delay in Contract Letting:

The adoption of 7 per cent maximum grades will increase the construction cost of grading and Retaining Walls about $35,000. It will increase the cost of right-of-way and property damage (County Charge) about $3,000, and will increase the cost of Town Bridge Structures about $2,500. This increase can be balanced by omitting concrete pavement on the new locations so that the total final cost of the project need not be increased over the old estimate. As a matter of fact, there is a distinct advantage in omitting the concrete pavement on new locations and deep fills, and substituting temporary gravel surfacing, as at such points it is impossible to successfully construct a rigid pavement in less than 2 to 4 years after the grading is completed. It is evident that the decision in regard to the use of 7 per cent maximum grades need not give much consideration to the factor of construction cost.

The adoption of 7 per cent maximum grades will make it necessary to get out entirely new plans for 6 miles of very difficult location. These plans can not possibly be completed before March 15 or April 1, and this delay is naturally annoying to the local people and possibly to the Commissioner. The local backers of the project believe that the plans can be easily and quickly gotten out to conform with the Federal Aid request, and they seem to think that we are stalling in this matter. This is quite natural as there has been considerable long rolling in connection with this road.

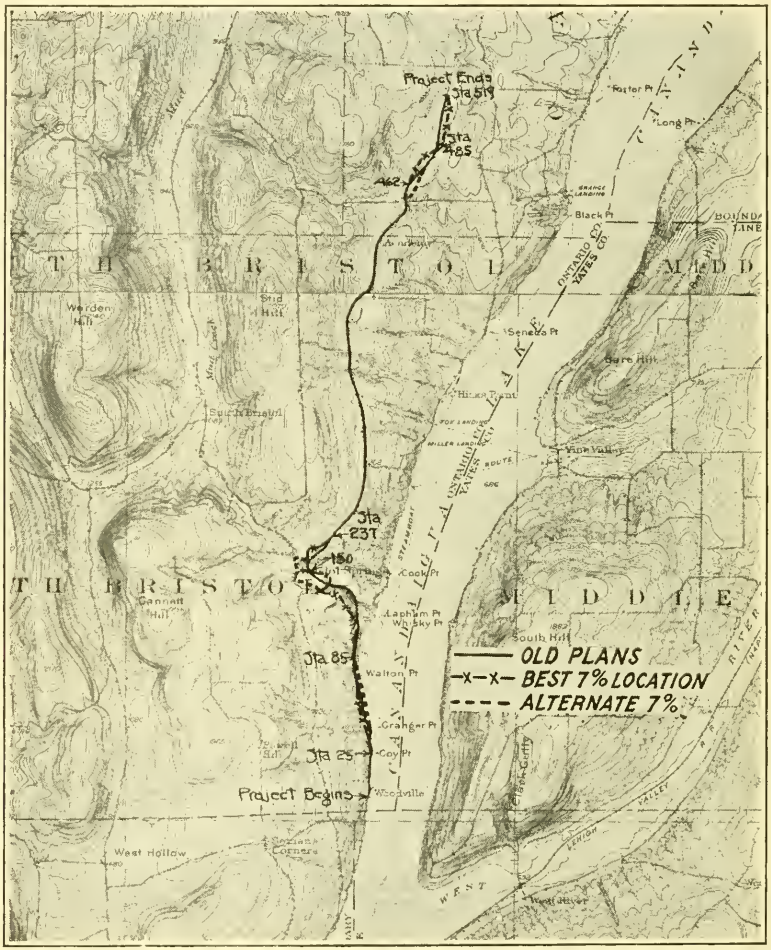

FIG. 206.—General map of relocations requested by U. S. Bureau of Roads.

An examination of the photographs at the end of the report shows the general character of the country, and any engineer will immediately realize that an economic location requires radically different survey and office design methods than usually employed for the ordinary highway in flat open country. It has been necessary to make a careful Stadia Contour Survey between the upper and lower limits of all possible locations in the really difficult topography, and then to make a series of trial projections to arrive at a fairly good and fairly economical location. These methods will result in large savings in construction cost which may easily total $20,000 to $40,000, and I trust that the Commissioner will not be too much influenced by a desire for speed in the preparation of the plans.

The necessary surveys will be completed by Jan. 1. The office force is well organized and this is a job where the advantage of careful engineering will be very evident in the matter of construction cost. The following engineering arguments and data give no weight to the matter of a 3 months, delay in the preparation of new plans.

Summarized Engineering Report:

The attached tabulation showing a summarized comparison of the 10 per cent and 7 per cent locations, will probably furnish all the information you will need at this time. This tabulation indicates in a general way that the adoption of 10 per cent or 7 per cent is largely a matter of personal judgment, as each line has certain advantages and disadvantages. The 7 per cent increases the grading cost but undoubtedly reduces the cost of motor operation, the exact amount of which is not known. The safety of the two lines are about equal. The service furnished to abutting properties and summer resort cottages is about equal with a slight advantage in favor of the original 10 per cent plans. It is certainly undesirable to increase the construction cost on this road and it is equally undesirable to lose the Federal cooperation or cause indefinite delay by combatting their request for a 7 per cent which undoubtedly has considerable merit. If the Federal Bureau stand pat on a 7 per cent maximum, it seems good sense to meet them in this matter and change type of pavement on the new locations and deep fills to a temporary gravel surfacing. This expedient will prevent an increase in the total construction cost of this project, and is good engineering procedure.

SUMMARIZED COMPARISON OF LOCATIONS

Section of road	Estimate cost of construction items affected by relocations		Right-of-way costs		Estimate town bridges		[1] Estimate capitalized traffic operative cost	
	10 per cent grade	7 per cent grade	10 per cent	7 per cent	10 per cent	7 per cent	10 per cent	7 per cent
Hawkins Hill Sta. 0–61....	$ 35,000	$ 49,000	$7,000	$ 8,000	$ 2,000	$ 3,300	$336,000	$318,000
Long's Gully Section 81–150.	74,000	69,000	1,300	1,900	9,000	8,000	310,000	282,000
[2] Standish Hill Section (Gully Line) Sta. 150–237.....	31,000	40,000	300	600	4,500	6,000	107,000	103,000
[3] Bird Hill Section 462–485..	5,000	18,000	200	500	500	1,100	80,000	70,000
McJannett's Hill Section 485–519.....	19,000	23,000	None	700	None	None	117,000	107,000
Totals.....	$164,000	$199,000	$8,800	$11,700	$16,000	$18,400	$950,000	$880,000

[1] Based on Traffic Cost Curve, page 596.

[2] The amounts tabulated for this section of the road are for the location we believe to be best for traffic, although it is not the cheapest in construction cost. There are two other possible lines which will be studied in detail if the Department decides to use the 7 per cent maximum rate of grade on this project. From the standpoint of cheapest construction cost, the road should go through Bristol Springs, which saves about $7,000 construction cost over the recommended line.

[3] A cheaper 7 per cent location with poorer alignment can be worked out on the upper side.

PART II. DETAIL ENGINEERING REPORT

General Conditions and Recommendations:

The plans previously submitted were prepared with the general idea of utilizing the existing road as much as possible and the location is based on 10 per cent maximum grades with excellent alignment. Ten per cent is not generally advocated but this road has a large percentage of scenic travel and for this class of traffic 10 per cent is perhaps allowable although personally I do not consider it advisable. Under these general specifications the old plans are an excellent piece of work and should serve this territory with moderate satisfaction. The local people use horse haulage for a considerable portion of the year and

state that if 10 per cent grades are retained they would like some provision made for gravel on the steep grades in place of concrete on account of team footing.

The Federal Bureau does not object to the details of the original location using the 10 per cent maximum but they do object to the general proposition of maximum grades of over 7 per cent. In order to get the 7 per cent maximum without too much increase in cost, I understand they are willing to approve a more crooked alignment than originally used provided extremely dangerous curves are not designed. The conflict between our original plans and the Federal Bureau request in regard to maximum grade is a matter of general policy and not of detail. It is the old conflict of differing judgment as to whether it is better to use a steep grade and straight alignment or a lighter grade and poorer alignment.

We agree that the general policy advocated by the Federal Bureau is usually sound, particularly on heavy travel roads, as it is easier in the future to eliminate alignment flaws by short additional improvements than it is to eliminate long steep dangerous grades requiring entirely new and lengthy relocations. There has undoubtedly been too much tendency in the last few years to save grading cost in order to put the money into higher class pavements. This general policy, however, cannot be arbitrarily applied to all cases and for this particular road there is some doubt as to the advisability of exactly complying with all the suggested relocations advocated by the Federal Engineers. That is, uniform maximum grades are not sound policy and each location is susceptible to special analysis.

This road is a Class II or Class III road from the standpoint of traffic volume; that is it will not probably carry more than 250 to 400 vehicles daily average. For roads of this class, it is difficult to justify average expenditures of more than $18,000 to $30,000 per mile although it has been customary for the past few years to spend from $25,000 to $35,000 per mile in ordinary topography. Due to unusually difficult topographic conditions, the original plans submitted were estimated to require a construction cost of approximately $54,000 per mile. If this road is considered as a separate project, it would be impossible to justify this expenditure from an economic standpoint but considering the facts that this project completes the state system along the west side of Canandaigua Lake which is a popular summer resort section and provides a good hauling outlet for a large section of farming and vineyard territory which is isolated from railroad facilities, it seems justifiable to expend any necessary amount to build a reasonably good state highway which will provide a means of safe travel the year round provided the cost is not made needlessly high. The necessary large increase in cost of this project over and above what can be economically justified and which must be charged to intangible benefit makes it desirable to use caution in approving additional refinements over and above essential requirements for fairly safe year round travel. Both of the Federal Bureau suggestions in regard to the use of 7 per cent maximum and the uniform use of 16-ft. concrete pavement in place of a varying pavement design increase the cost. Their request for the 7 per cent maximum is reasonable in the main with minor exceptions later discussed and I am in favor of complying with their request in this count although personally I do not favor the Bird Hill Relocations and believe there is considerable doubt as to the value of the Standish Hill Relocation. Their request for concrete pavement 16 ft. wide for the entire length is not sound in my opinion due to the factor of needless increase in construction cost and the danger of settlement on high fills and new locations.

Detail Comparison of Locations:

For the purpose of discussing the details of the proposed locations, the road is divided into five sections. Hawkins Hill Section Sta. 0–81 of the Old Plans. Long's Gully Section Sta. 81–150 of the Old Plans. Standish Hill Section Sta. 150–237. Bird Hill Section Sta. 462–485 and McJannett's Hill Section Sta. 485–519. Profiles and sketch plans accompany this report.

Hawkins Hill Section:

The Federal Engineers suggested a 7 per cent location on the lower side of the old 10 per cent location (east side) Sta. 33–85. A careful study and the collection of considerable data not available at the time the Federal inspection was made proved quite conclusively that the best location for the 7 per cent location in this section lay on the upper or west side from Sta. 25–63. The tabulation of the data comparing this location with the original 10 per cent grade is given on page 588. The 7 per cent location is probably justified on this section.

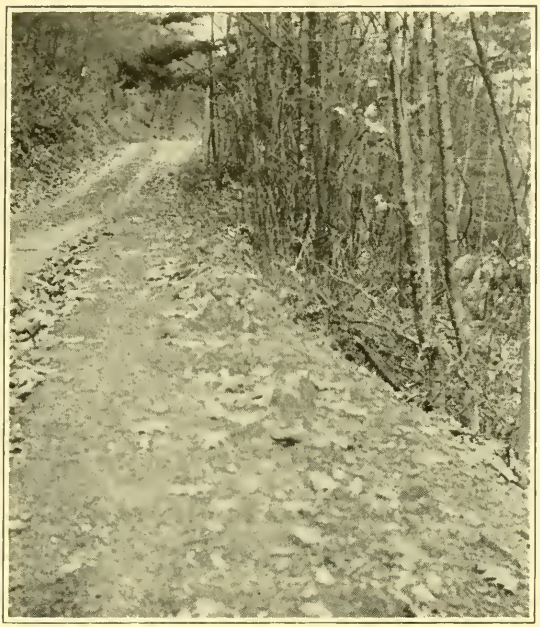

FIG. 207A.—General character of location, Sta. 40 to 50.

FIG. 207B.—General character of location, Sta. 50 to 60.

FIG. 207*C*.—General character of location, Sta. 50 to 60.

FIG. 207*D*.—General character of location, Sta. 120 to 140.

FIG. 207*E*.—Stadia survey party organization.

FIG. 207*F*.—General character of location, Bird Hill Section.

Long's Gully Section:

The Federal suggestion in regard to the 7 per cent location from 81 to 150 called for shifting west on the same hillside used by the 10 per cent from 81 to 110 and recommended following up Long's Gully to Bristol Springs crossing the Gully at our old location.

Our final study indicates that the shift west Sta. 81 to 95 is desirable but that from this point the best solution calls for a radical change of line crossing the Gully about 2,000 ft. above the old location. The comparative engineering data is tabulated on page 589. The Long's Gully Section can undoubtedly use a 7 per cent maximum to advantage.

Standish Hill Section:

This section involves a more complicated analysis. The original plans shorten the existing unimproved road by about a half mile by means of a cut off east of Bristol Springs. This cut off does not in any way affect the length of travel between Naples and Rochester and shortens the travel between Naples and Canandaigua about a half mile.

The Federal suggestion involved passing through Bristol Springs with the longer length of travel. The attached tabulations of the alternate routes "A", "B", "C" and "D", pages 589 and 590, show that from the standpoint of first cost the line through Bristol Springs ("B Line") is the cheapest but that if the items of construction cost are balanced against the increased cost of motor operation, the cut off line "C" is probably the best investment for the community. There is, however, considerable doubt whether any 7 per cent location on this section has sufficient advantage over the 10 per cent to warrant the change. If the Federal Bureaus are more or less committed by general policy to a 7 per cent maximum, it is not worth chewing the rag over provided they act reasonably in regard to pavement cost decrease.

Bird Hill Section:

No specific recommendations in regard to location were made by the Federal Engineers. The best location seems to lie in the Gully but this is an expensive piece of line and the advantage of the 7 per cent over the 9 per cent actually used seems to be slight. I cannot recommend this location except on the score of meeting an arbitrary demand by the Office of Public Roads. A somewhat cheaper location with poorer alignment can be developed on the upper side. The tabulation of data on this section is found on page 590.

McJannett's Hill Section:

The relocation worked out is so obviously better than the old plans that no discussion is necessary. Data is tabulated on page 591.

Comparison of Locations

Hawkins Hill Section Sta. 0–81.

	Plans Previously Submitted	New Proposed Plans
Length of travel	8,080	8,050
Length of new road	8,080	8,050
Maximum grade, per cent	10	7
Minimum sight distance, feet	310	260
Minimum radius curvature, feet	716	382
Estimated capitalized operation per 400 tons daily average	$336,000	$320,000
Estimated cost grading, retaining wall, guard rail and clearing	$34,300	$48,300
Amount of excavation, cubic yards	34,800	48,000
Amount of wall, cubic yards	None	20
Amount of guard rail, posts	1,000	900
Clearing and grubbing	1.5 acres @ $300 = $450	2.5 acres @ $300 = $750
Right of way	Cottage sites 1.0 acres	Cottage sites 1.0 acres
	Gully land 1.0 acres	Gully land 3.5 acres
	Farm land 1.0 acres	Farm land 1.0 acres
	Vineyard 0.8 acres	Vineyard land 0.8 acres
	Moving buildings 12	Moving buildings 13
Town bridges	Sta. 40 6 × 6 × 30 = $700	6 × 6 × 110 = $2,000
	Sta. 63 6 × 6 × 45 = $1,300	6 × 6 × 45 = $1,300

Remarks: The new location is probably justified. It increases the grading cost about $14,000. The right of way cost about $1,000. The town bridge cost about $1,300. It reduces the cost of motor operation probably enough to warrant the increased construction cost. Safety of travel is about the same and is good enough for reasonably careful drivers. It reduces length of road about 30 ft. The increased construction cost can be eliminated by the use of gravel surfacing in place of concrete on the deep fills and new side hill location

Comparison of Locations

Long's Gully Section "A" Line Sta. 81—154 "A," Sta. 81—150 Old Plans:

	Old Plans	New Plans
Length of new road, feet	6,900	7,300
Maximum grade, per cent	10	7
Minimum sight distance, feet	300	250
Minimum radius curvature feet	520	370 ft. on 7 % grade 175 ft. on 3 % grade
Estimated capitalized cost motor operation per 400 tons daily average	$310,000	$285,000
Estimated cost grading, retaining wall and clearing	$40,000	$33,000
Estimated cost of concrete pavement	$34,000	$36,000
Amount of excavation, cubic yards	44,400	31,000
Amount of wall, cubic yards	None	400
Clearing and grubbing, acres	3.2	4.7
Right of way	Gully..... 5.0 acres Farm..... 7.0 acres	Gully..... 8.0 acres Farm..... 2.3 acres Vineyard..... 1.8 acres Orchard..... 0.2 acres Moving buildings... 1
Town bridges	Sta. 116 + 61.	

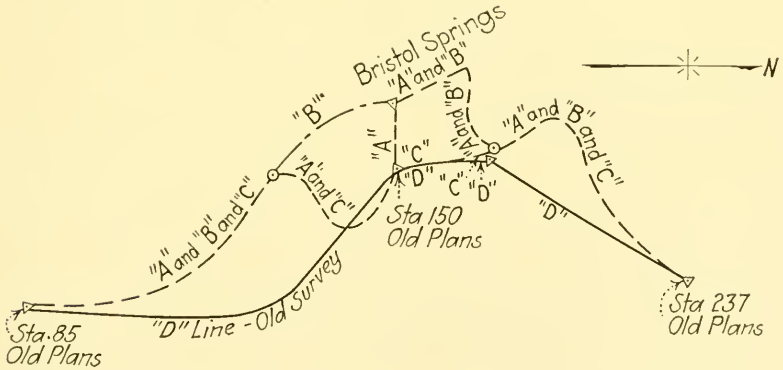

Fig. 208.—Sketch showing relation of alternate locations, Sta. 85 to 237.

WOODVILLE RELOCATION COMPARISON OF LOCATIONS STA. 81–237 QUANTITIES COST (see Fig. 208)

	Old plans "D" line	New plans—gully "C" line[1]	New plans "A" line	New plans—via springs "B" line[2]
Length of travel				
Length of new road, feet	9,770	10,500	12,670	12,040
Maximum grade, per cent	10	7	7	7
Minimum sight distance, feet	300	250	250	250
Minimum radius of curvature,	382 ft. on 10 %	175 ft. on 3 %	175 ft. on 3 %	200 ft. on 2 %
		370 ft. on 7 %	370 ft. on 7 %	370 ft. on 7 %
Estimate capitalized cost of motor operation	$417,000	$385,000	$451,000	$416,000
Estimate cost of grading, retaining wall, guard rail, clearing and pavement	$106,000	$111,000	$104,000	$102,000
Estimate cost of right of way	$ 1,600	$ 2,500	$ 5,000	$ 5,000
Estimate cost of town bridge	$ 13,500	$ 14,000	$ 9,500	$ 10,500

[1] NOTE: "C" Line location recommended as added benefit to traffic is far in excess of immediate loss due to added construction cost.

[2] NOTE: "B" Line location recommended if cheapness in construction cost is prime requisite.

QUANTITIES

Excavation, cubic yards	63,400	57,000	37,250	39,400
Wall, cubic yards	.....	400	400	400
Guard rail, posts	1,000	600	350	350
Clearing and grubbing, acres	3.2	4.7	4.7	4.6
Pavement, square yards	17,400	18,850	22,500	21,400
Right of way.				
Gully, 5 acres—$250 Farm, 9 acres—$1,600	Gully, 8 acres Farm, 6.3 acres Vineyard, 1.8 acres Orchard, 0.2 acres Moving building, 1	Gully, 8 acres Farm, 5 acres Vineyard, 2.5 acres Orchard, 1.37 acres Moving building, 1	Gully, 9 acres Farm, 3.5 acres Vineyard, 2.25 acres Orchard, 2 acres Moving building, 1	
Town bridges.....	116+61, 9′ by 9′ by 200′, $9,000 154+25±, 10′ by 10′ by 90′, $4,500 134+50, 9′ by 9′ by 180′, $8,000 145+25+, 10′ by 10′ by 120′, $6,000		134+50, 9′ by 9′ by 180′, $8,000 175±, 10′ by 10′ by 30′, $1,500 134+50, 9′ by 9′ by 195′, $9,000 175±, 10′ × 10′ × 30′, $1,500	

COMPARISON OF LOCATIONS

Bird Hill Sta. 462—485 + 55:

	PLANS PREVIOUSLY SUBMITTED	NEW PLANS PROPOSED
Length of travel, feet	2,355	2,375
Length of new road, feet	2,355	2,375
Maximum grade, per cent	9.0	7.0
Minimum sight distance, feet	330	250
Minimum radius curvature, feet	716	570
Estimated capitalized cost motor operations per 300 tons daily average	$79,000	$71,000
Estimated cost grading, retaining wall and clearing	$5,100	$18,000
Amount of excavation, cubic yards	5,600	7,900
Amount of wall, cubic yards	None	1,000
Clearing and grubbing, acres	0.1	3
Right of way	0.1 acres poor land 1.1 acres farm	0.4 acres apple orchard 3 acres poor gully land
Town bridges,	9 ft. span 15 ft. long	6 ft. × 6 ft. C.B. 55 ft. long

REMARKS: There seems to be considerable doubt as to the advisability of the new location. The construction cost is raised about $13,000. The right-of-way cost is raised about $300. The town bridge cost is raised about $600. The theoretical traffic operation saving does not probably warrant an increase in construction cost of this road of over $6,000 to $8,000. For a heavier traffic road carrying 1,000 to 1,500 tons daily, the relocation could be easily justified on this score. Under the circumstances, however, that the U. S. Bureau of Roads are more or less inclined to demand the 7 per cent maximum, it seems good sense to comply with their request and get the required cooperation, provided they approve a reduction in paving cost to balance an increased grading cost.

(*McJanett's Hill Section, Sta.* 485+55–522+55)

	PLANS PREVIOUSLY SUBMITTED	NEW PLANS PROPOSED
Length of travel	3,700	3,850
Length of new road	3,400	3,850
Maximum grade, per cent	9.0	5.0
Minimum sight distance, feet	330	600
Minimum radius curvature, feet	955	716
Estimated capitalized cost of motor operation for 300 tons daily average	$117,000	$107,000
Estimate cost concrete pavement @ $2.80 per square yard	$17,000	$19,000
Estimate cost grading, wall and clearing	$1,800	$3,600
Amount of excavation, cubic yard	2,000	4,000
Amount of wall	None	None
Clearing and grubbing	None	None
Right-of-way	None	None
Right-of-way	None	5 acres ordinary farm land
Town bridges	None	None

REMARKS: Considering future service, the new location is apparently justified although it increases the construction cost by about $4,000 and the right of way cost about $700. The theoretical saving in travel cost apparently warrants an increase in construction cost of from $7,000 to $10,000.

Survey and Office Methods Used:

Limits of possible locations traced by means of Abney Hand Level and Brunton Pocket Transit working both from summits down and low control up.

Reconnaissance report based on Transit Stadia line and profile with cross slopes taken at short intervals. Excavation figured on basis of cross slopes (see table, page 593) with allowance for profile irregularities for sections of the road where the grade contour can be followed closely. For large cuts and fills excavation and embankment estimated on basis of center line cut or fill.

Final location and estimate based on very careful stadia contour survey. Checking with old survey for distance, angle and elevation at short intervals.

Instrument rated for distance and constant F. and C. Both corrections considered in computing all shots. Special reduction diagram prepared. Survey plotted 30 ft. to 1 in. on system of coordinate control. Projected locations figured on basis of coordinate corresponding with survey coordinates. Apparent maximum error in horizontal location of projected lines not exceeding 0.5 ft. Apparent error in stadia levels from cross-checks on old survey not to exceed 0.2 ft. with tendency to equalize. Probable average error not over 0.1 ft. Cross-sections projected and plotted on usual scale 1 in. = 5 ft. Quantities figured in usual manner.

General Specifications Engineering Location and Design:

The general alignment specifications used in locating the proposed 7 per cent maximum to comply with the Federal request are as follows:

Minimum sight distance, feet	250
Minimum radius of curvature on outside curves on grades over 3 per cent, feet	370
Minimum radius of curvature on inside curves on grades of 3 per cent or less, feet	175

Maximum grades compensated on all sharp curves enough to permit future straightening with a future maximum of 7 per cent.

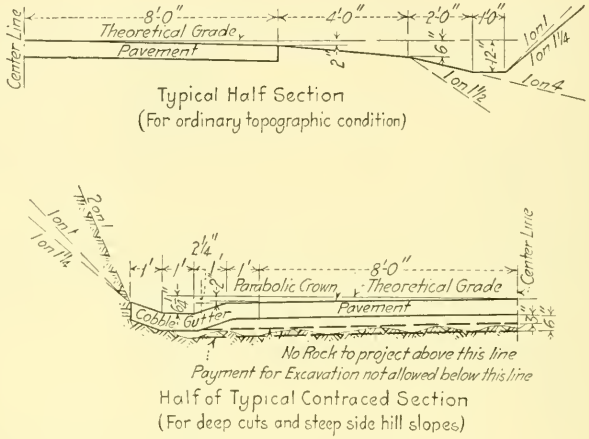

Fig. 209.—Typical proposed sections.

These specifications, which will produce a good usable highway in rough hill country, affect cost of construction, right of way, bridges and travel service as shown in the preceding table accompanying the general report to the Commissioner (see page 583).

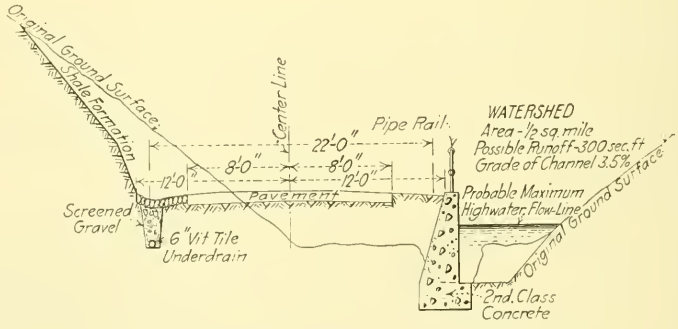

Fig. 210.—Special section (Bird Hill Section).

Typical cross-sections shown by Figs. 209 and 210. Fill slopes 1½ to 1; cut slopes in shale cuts 2 on 1 based on our previous experience with this formation verified by B. R. and P. practice. Cut slopes for shallow cuts in gravel and loam 1 to 1; cut slopes in gravel deep cut 1 on 1¼. Balance ratios cut to fill. Shale formations 1 to 1. Loam and gravel 1.10 to 1.40 depending on volume of fills and amount of sod or duff.

TABLE OF CUT AREAS IN SQUARE FEET FOR BALANCED SIDE HILL SECTIONS

Cut slopes 1 on 1¼. Fill slopes 1 on 1½

Cross slope in degrees	Area of cut in square feet	
	Normal section	Contracted section
2	5	
3	7	
4	9	
5	11	
6	14	
7	17	
8	20	
10	25	18
11	..	20
12	30	23
13	..	26
14	..	30
15	..	33
16	..	36
17	..	39
18	..	43
19	..	47
20	..	52
21	..	58
22	..	65
23	..	72
24	..	80
25	..	90
26	..	101
27	..	115
28	..	135
29	..	162
30	..	204

Add from 20 per cent to 50 per cent for profile irregularities.

TABLE OF CUT AND FILL AREAS SQUARE FEET

Based on level line for different center line depths of cut and fill

Cut slopes: 1 on 1¼. Fill slopes: 1 on 1½

In feet depth on center line	Cut areas in square feet		Fill areas—square feet, normal section
	Normal section	Contracted section	
0	25	.....	0
1	58	.....	10
2	95	.....	35
3	139	.....	65
4	177	.....	100
5	220	.....	137
6	269	.....	175
7	316	.....	215
8	368	.....	260
9	423	.....	308
10	478	385	360
11	...	436	413
12	...	490	471
13	...	545	532
14	...	603	595
15	...	662	660
16	...	725	730
17	...	790	800
18	...	859	877
19	...	928	955
20	...	1,002	1,035
21	...	1,077	1,120
22	...	1,155	1,206
23	...	1,235	1,295
24	...	1,318	1,386
25	...	1,402	1,485
26	...	.....	1,580
28	...	.....	1,790
30	...	.....	2,015
32	...	.....	2,240
34	...	.....	2,480
36	...	.....	2,730
38	...	.....	3,000
40	...	.....	3,280
42	...	.....	3,580
44	...	.....	3,880
46	...	.....	4,190
48	...	.....	4,520
50	...	.....	4,850

Basis of Cost Estimates:

The following unit prices are used in deriving cost estimates. These prices correspond with the prices used on the last official estimate dated Sept., 1922.

Clearing and grubbing	$200 to $500 per acre
Unclassified excavation	0.90 per cubic yard
Concrete wall (including cement)	12.00 per cubic yard
6-in. Concrete pavement (including cement and steel)	2.80 per square yard
9-in. Bituminous macadam	2.10 per square yard
9-in. Gravel surfacing	0.75 per square yard

Right-of-way Allowances:

Poor gully land (timbered)	$ 50 per acre
Ordinary farm fields	150 per acre
Vineyards	500 per acre
Orchards	700 per acre
Moving houses	1,000 each

Town Bridges:[1]

6 ft. by 6 ft.	$20 per foot of length
7 ft. by 7 ft.	25 per foot of length
8 ft. by 8 ft.	32 per foot of length
9 ft. by 9 ft.	40 per foot of length
10 ft. by 10 ft.	50 per foot of length

[1] Costs are for structures exclusive of excavation, an additional allowance made for excavation.

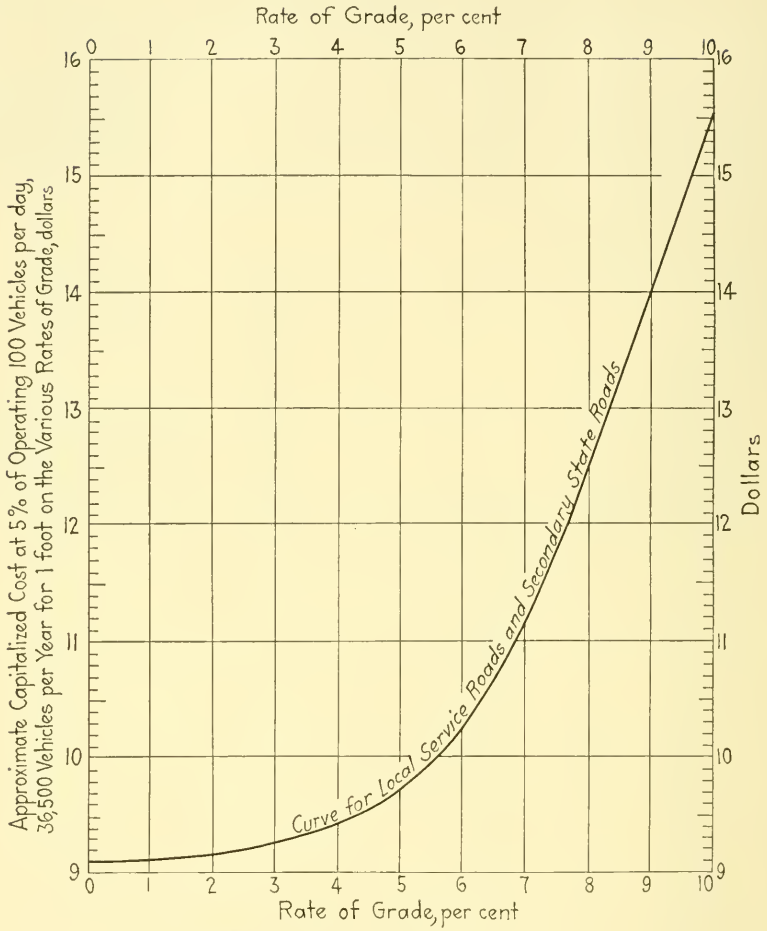
Rate of Grade, per cent
0 1 2 3 4 5 6 7 8 9 10
16 15 14 13 12 11 10 9
Approximate Capitalized Cost at 5% of Operating 100 Vehicles per day, 36,500 Vehicles per Year for 1 foot on the Various Rates of Grade, dollars
Curve for Local Service Roads and Secondary State Roads
Dollars
Rate of Grade, per cent

FIG. 211.—Basis of traffic cost estimates (see Fig. 5, page 16).

APPENDIX C

HEAVY TRUCK WEIGHTS OBSERVED ON MASSACHUSETTS ROADS[1]

Both loadometers and platform scales have been used by the division of highways Massachusetts Department of Public Works, to check the weights of motor trucks. The following comment on the results is from a discussion by A. P. Porter, inspector, before the Boston Society of Civil Engineers:

During 1920, 90 trucks were weighed by the loadometers, and in 1921, 100 trucks by the loadometer and 400 by platform scales. The first two jacks used were calibrated to 20,000 lb. each, but the second pair, supposed to be an improved model, have a capacity of only 15,000 lb. each. The first truck I met after I began using these improved jacks was too heavy to be weighed with them and I had to resort to a neighboring 20-ton platform scale. The rear axle of this truck weighed 33,200 lb., the heaviest I ever weighed.

The largest gross weight of a four-wheeled truck and load which we actually weighed was 38,300 lb., and the largest load on six wheels was 40,000 lb. The accompanying table shows the maximum loads encountered. Undoubtedly there were some larger than these which did not happen to come our way.

MAXIMUM TRUCK WEIGHTS IN MASSACHUSETTS, 1920, 1921

Rated capacity tons	Character of load	Type of body	Actual gross weight, tons	Weight of load, tons	Overall length, feet	Length wheel base, feet	Weight on front axle, tons	Weight on rear axle, tons
7½	Leather	Platform	22	16	24	14	5	17
7½	Cr. stone	Dump	18	11	23	14	3	15
7½	Beef	Platform	17	10.5	25	15	3.4	13.7
5½*	Wool	Platform	22[1]	11.5[1]	45[1]	14	3[2] 4.2[3]	10.5[2] 4.3[3]
5*	Boiler	Platform	23	14	37½[1]	15.5	3	10[2] 10[3]
....	Road oil	Tank	16½	6½	23	14	3.3	13.2
....†	60-ft. I-beams	Special	29	16½	99	11	2[4] 2[4]	4[4] 6[4] 15[3]
5½	Sugar	.....	18¾	12½	....	13	2.1	16.6
6	Sugar	Stake	19.1	13	....	....	4	15.1
7½	Gravel	Dump	18¼	12	....	13.2	3	15¼
6½	Grapes	.....	18¾	12½	....	....	3¾	15
10‡	Jars in ice	Enclosed	20	12	....	12.2	3	8[2] 9[3]
5‡	Boiler	Platform	20	10	....	15½	3	8[2] 9[3]
5	Asphalt shingles	Platform	18¼	12¼	....	15.6	4¼	14
5½	Groceries	Platform	18¼	12½	....	15.7	4¼	14
5½	Sugar	Platform	18½	13	....	12.2	3¾	14¾
Special	.....	.....	20	....	30	12	6	14

* For truck only in truck-trailer combination;† two tractors and semi-trailer,‡ tractor and semi-trailer;[1] includes truck and trailer;[2] truck;[3] trailer;[4] tractor. The "Special" truck is the Massachusetts standard for design of highway bridges.

[1] From *Eng. News-Record*, April 20, 1922.

The proportion of the weight which comes on the rear axle of a truck varies from 70 to 87 per cent. It is not constant for a certain truck. As more load is added, the percentage on the rear increases. It varies also with different makes of truck, different classes of commodities, length of wheel base, length of body, overhang, and how the load is placed. Loads of wool or cotton are sometimes piled forward over the cab. The average per cent on the rear, for all makes, is about 78.

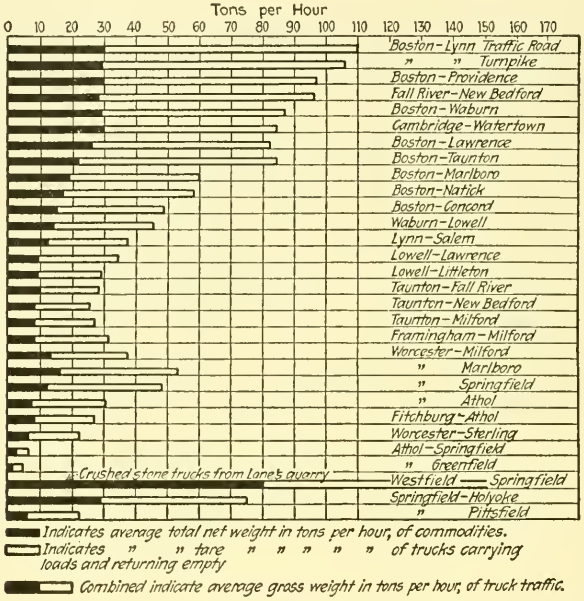

FIG. 212.

The legal limit in Massachusetts for the weight of truck and load is 14 tons, and outside the metropolitan parks and sewerage districts there is also a limit of 800 lb. per inch width of tire. Since the largest tire practicable is 14 in. wide or its equivalent, two 7-in. tires, this practically limits the legal axle load to 22,400 lb. even with the largest tires. When the weight of the truck and load was over the legal limit several hundred pounds or more, we summoned the driver to court. In 1921 we had 116 cases in court and secured a verdict of guilty in 109 cases.

Sometimes we made the truckman remove part of his load. On one occasion in Reading, I stopped a truck going from Boston to Lowell which weighed 38,300 lb., and another owned by the same company going to Lawrence which weighed 34,100 lb. When told they could not proceed, they telephoned to Boston for another truck, which came out and took 25 bbl. of sugar off one truck and 17 off of the other.

When we started the investigation there were three facts we wanted to determine:

1. *The Maximum Load.*—Actual weight of heaviest truck load and how its weight is distributed on the wheels. This is to be used as a basis for computing the greatest stresses in the pavement and in bridges.

2. *Overloaded Trucks.*—The ratio of the actual load to the manufacturers' rated carrying capacity is called the "load factor." While we found some trucks carrying as much as two or three times the rated capacity, the average load factor for all the trucks carrying any load is about 1, and taking into account the trucks returning empty the average load factor is about 0.5.

3. *Intensity of Traffic.*—A highway engineer is often called upon to compare the traffic over one road with that over another. For this purpose it is necessary to stop every heavy truck passing a certain point, ask the driver a number of questions regarding the weight of

his truck and load, and find the total weight of all the trucks in a given period of time. I adopted "tons-per-hour" as being probably the most convenient unit to express the volume of traffic. For instance, if one road carries ten times as many tons per hour as another, it is reasonable to suppose that the former road will wear out about ten times as fast as the latter and cost ten times as much to keep up, other things being equal.

The diagram herewith showing intensity of truck traffic gives first the average weight in tons per hour of the commodities carried, *i.e.*, the pay load; and secondly, the average gross weight of the trucks and loads passing that point, including the weight of the trucks returning empty. The former is an index of the relative economic value of the road to the community. The latter is a measure of the relative wear due to trucks. Pleasure vehicles and light trucks are not included in this diagram.

We divided the commodities carried into five groups: (1) Crushed stone, gravel, etc.; (2) oil, gasoline, and tarvia in tank bodies; (3) groceries, meat and drinks; (4) wool, cotton and dry goods; (5) machinery, lumber and furniture.

Our analysis of these figures shows some interesting conclusions—among others, that the loads going out from the city are very much greater than the loads going in toward the center. About 75 per cent of the net load on any one of the through routes is going out from Boston, and only 25 per cent coming in. If these could be more nearly balanced, the efficiency of this kind of transportation would be very much increased.

APPENDIX D

Introductory Note.—As a further evidence of the essential correctness of the Design Values assigned to S (Tension) Chap. II, page 106 the following recent report published since the preparation of the manuscript is included as Appendix D.

The report is given in full. Some of the data and recommendations do not agree with the text of this book in all particulars. This should be of interest to the reader in supplying a somewhat different point of view indicating the points of disagreement and uncertainty in pavement design (1923).

PRACTICAL LESSONS FROM THE BATES ROAD TESTS[1]

Completion of the traffic tests on the Bates test road in Illinois permit certain tentative conclusions which can be put to immediate use in designing paved roads. In general the tests have shown first that there must be strict truck-load regulation if paved roads are to endure, and second that greatest pavement endurance is secured by a slab which is considerably thickened at the edges. Both of these practices have been laid down as requisites for the future highway operations of the state of Illinois.

A description of the Bates test road and details of the construction of each section were published in *Engineering News-Record* of Aug. 18, 1921, p. 274. In the issue of Aug. 10, 1922, p. 236, the results of the traffic tests up to and including the fifth increment of loading were published. Briefly, the plan of the traffic test was to impose on the 2-mile road consisting of 63 different sections of pavement, a loading shown in the table on page 602. Eighteen 3-ton trucks were used for applying the loads.

Tentative Conclusions.—With the completion of the tests the greatest traffic imposed upon any section was 377,460 tons. Of this 198,000 tons were imposed by trucks loaded to the legal limit of 8,000 lb. on each rear wheel. Only nine of the original 63 sections came through without a break. Since four of the sections had breaks which were obviously caused by abnormal conditions, thirteen sections may be considered as having satisfactorily sustained the traffic test. The final records are not yet fully analyzed, but certain general comparisons and tentative conclusions are possible.

1. A difference in the thickness of base, thickness of brick or type of brick, apparently had no consistent effect upon the load-supporting capacity of bituminous filled brick on macadam base. All five sections failed at approximately the same time and to the same extent. This does not seem logical and studies will be made in an effort to fix the cause of the apparent inconsistency.

2. No consistent ratio of strength to thickness of base appears in sections of asphaltic concrete on macadam base. Apparently traffic-supporting capacity increases with an increase in thickness of asphaltic concrete top.

3. The assumption made at the beginning of construction that an asphaltic concrete wearing surface on a concrete base would have a traffic supporting capacity equal to that of a concrete pavement having a thickness equal to that of the base plus 1 in. seems to have been a fair guess. Additional thickness of top apparently adds strength to the pavement. It is further evident that increased base thickness is accompanied by increased strength.

4. Wide variation is noticed in comparing sections having the same base and top thickness, but having lean and rich base mixes.

[1] *Eng. News Record.*

5. The original assumption that a bituminous-filled brick wearing surface on a concrete base has a strength equal to that of a concrete slab having a thickness equivalent to that of the base plus ½ the thickness of the brick surface was apparently incorrect. In practically every instance the concrete sections proved of greater strength than their supposed equivalent in bituminous filled brick.

6. There appears to be no obvious difference in the resulting strength of the 2 kinds of brick (lug and lugless), the bases being the same. In each case the artificially-cut joint was inadvertently made in the part of the sections laid with lug brick; and to this fact is attributed the greater number of breaks occurring in the sections of this type. Had these joints been cut in both the lug and lugless sections, it is believed the breaks would have been equal in number in both types of brick sections.

7. Although no direct comparisons can be made between 3-in. and 4-in. brick, the bases being the same, the indications are that the added inch of brick is probably effective in producing greater strength. In comparing sections where the total thickness of the pavement is about the same, but variations are present in the thicknesses of the base and brick surface, a great inconsistency is noticed. The comparative effect of rich and lean base mixes seems also to be inconsistent.

8. In comparing the various cushions which were used under the surfaces, it seems to appear that the mastic cushion (in this case 10 per cent Tarvia B mixed with sand) is superior to the sand and sand-cement cushion. In regard to the use of sand and mastic cushions, it can be said that previous to the application of traffic on the road, a difference was noted in the surface of the brick in these sections. In the sand cushioned sections it was noted that an occasional row of brick across the entire width of pavement had settled immediately over a crack in the base. It is thought that this settlement was due to the sifting of the sand from the section through the crack. Although cracks were present in the base of the mastic-cushioned section the cohesiveness of the cushion prevented any sifting of the material, with the result that no settlement in the brick took place.

9. The original assumption that the brick surface in monolithic pavement acts as a unit with the concrete of the base, thus forming a truly monolithic slab having the same carrying capacity as an equal thickness of concrete, was disproved early in the traffic tests. Before the truck traffic was started, a number of areas were recorded where the bond between the grout-filled brick surface and the base was distinctly broken. Additional areas of this character continued to develop during the test. Under the trucks, the brick surface and the base in these areas acted as independent superimposed units in supporting the loads. The brick surface usually failed first by a shattering of the bond between the individual bricks, the base then being called upon to support a much greater proportion of the total load. Usually base failure soon followed. It was clearly evident that the strength of a so-called monolithic section was less than that of a concrete section of the same thickness.

10. In comparing the value of an added inch of brick with an added inch of concrete base, the total thickness remaining the same, it was noticed that the thicker base section has the advantage.

11. An increase of total thickness appears to add strength. That is, a 4-in. brick on a 2-in. base shows greater strength than a 3-in. brick on a 2-in. base.

12. Indications are that a richer mix of concrete in the base is better than a lean one.

13. Soon after starting traffic, it developed that the sections containing special cements or other chemicals showed less strength than the plain concrete sections of the same thicknesses.

14. Sections containing certain special features of design, consisting of transverse and longitudinal joints with marginal steel, showed greater strength than the plain concrete sections of the same thicknesses.

15. A comparison between the sections having imbedded steel gives the impression that the sections containing wire mesh showed the least strength for their thicknesses.

16. Sections containing wire mesh seemed to show some indications of greater strength than plain concrete having the same thickness.

TABLE I.—LOAD INCREMENTS AND THE NUMBER OF APPLICATIONS OF EACH

Increment number	Load, pound on each rear wheel	Load, pound on each front wheel	Gross load	Net or live load in pounds	Number of round trips	
					Day	Night
1	2,500	2,250	9,500	.....	1,000	
2	3,500	2,150	11,300	.....	2,167	1,033
3	4,500	2,000	13,000	1,700	2,000	1,000
4	5,500	1,900	14,800	3,500	2,000	1,000
5	6,500	1,800	16,600	5,300	2,000	1,000
6	8,000	1,930	19,860	8,560	5,000	5,000

17. A comparison of sections containing longitudinal control joints and those in which no joint was placed appears to give the former the advantage of strength.

18. In the plain concrete sections the thicknesses of the slabs were a measure of their strengths.

19. *The behavior of all of the 63 sections demonstrates the fact that if traffic can be kept away from the edge of the pavement, fewer failures will result.* Under every increment of load, except the first, the number of failures occurring on the south side exceeded to a very great extent those on the north side. The line of traffic in all runs except the first, was such that the outer rear wheels of the trucks traveled 2½ ft. from the edge of the pavement on the north side and directly on the edge of the south side.

Strength Theory of Rigid Pavements.—In *Engineering News-Record* of Feb. 3, 1921, p. 210, Clifford Older, State Highway Engineer of Illinois, called attention to the apparent weaknesses of rigid pavements at corners formed by the intersection of transverse cracks or joints with the edges of the pavements. A tentative formula for pavement design was suggested which was based on the assumption that such corners should be designed as unsupported cantilevers. This formula for slabs of ordinary design without special provisions for strengthening the edges was as follows:

Stress equals three times the load divided by the square of the depth of the slab:

$$S = \frac{3W}{d^2}$$

Transposing this formula,

$$W = \frac{Sd^2}{3}$$

If, then, the assumption upon which this formula is based is true, by substituting for S the modulus of rupture of the load-carrying element of the slab design, the breaking load for any thickness may be determined.

It is interesting to compare the behavior of the rigid sections of the Bates Road with this formula.

In the figure the theoretical breaking load curve is plotted on the basis of the average modulus of rupture of the test pieces of all concrete sections and all others having concrete bases. The breaking load points in this diagram are plotted in the same horizontal position relative to this breaking load curve as they hold to the average modulus of rupture curve of their respective series. It is noticeable that even as so plotted, the points fall in rather a wide band. Such an occurrence is inevitable considering the fact that even in carefully controlled operations, accidents of construction may influence the strength of the pavement slab. Further, the temperature conditions affecting the closing of transverse joints and cracks, therefore greatly affecting the carrying capacity of the weak corners, tend to produce erratic results. Again, the load increments vary one from the other by rather wide stages, which might easily mean that the critical load for a given thickness was less than the one recorded. No attempt was made to take this factor into account in evaluating the critical load breaks, as previously described. The figure shows also a curve in which the

load causing fiber stress equal to that of one-half of the average modulus of rupture is plotted against the thickness.

The fatigue tests which have been carried on by the Illinois Division of Highways for about 18 months indicate conclusively that concrete may resist bending loads indefinitely if such loads do not cause fiber stresses in excess of one-half of the modulus of rupture of the concrete. Inasmuch as it was impossible to operate the trucks a sufficient number of trips for each increment to cause fatigue, the plotted points in all diagrams without doubt are but little affected by fatigue breakage. The laboratory tests show that where the loads applied produced a fiber stress of from 5 to 10 per cent in excess of one-half of the modulus of rupture, fatigue may not follow for from 5,000 to 40,000 repetitions. Loads which produce fiber stresses in excess of 60 per cent of the modulus of rupture are usually followed by breakage after a comparatively few repetitions.

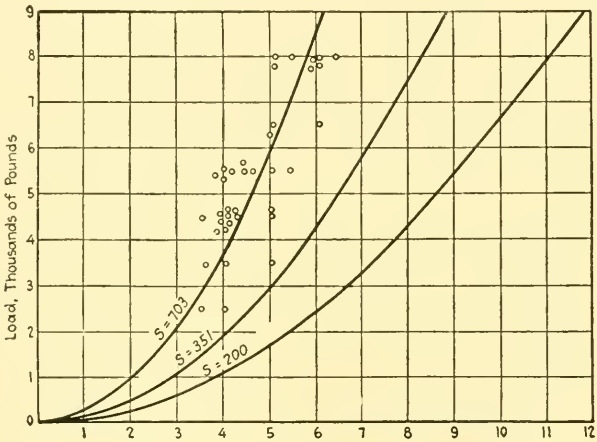

FIG. 213.—Bates road (record of actual failures). Cement concrete pavements.

It seems safe therefore to conclude that had the number of applications of each increment been much greater—say 30,000 to 40,000— the breaking load points would have fallen in the main between the curve passing through points representing a fiber stress of 703 and that representing a fiber stress of 351.

In the figure is also plotted a curve representing a fiber stress of 200 lb. per square inch which was proposed as a working formula in 1920. Had the various sections of the Bates Road been designed in accordance therewith, no breakage of any kind would have appeared under increments equal to the designed load. In none of the sections of the Bates Road, except 63A and 63B, which represent the Illinois 1921 standard, was provision made for strengthening corners by doweling.

While the theory on which this formula is based is perhaps not yet fully established, nevertheless the empirical data furnished by the traffic tests seem to be sufficiently confirmatory to justify its use at least until something better is found.

By means of one or more continuous dowel bars along the edge, it is believed that adjacent corners may be made to act together and thus the breaking and working loads may be increased materially, or perhaps even doubled. Further, it is easily conceivable that if in addition to dowel bars the edges are thickened, they may be made stronger than other portions of the slab. It is, then, important to determine where next to look for trouble; and eventually determine how the slab should be designed for balanced strength throughout.

APPENDIX E

STREET WIDTHS

This book is primarily concerned with the design of rural highways but in connection with rural improved highways it is often necessary to design short stretches of village or city street pavements as connecting links on such systems and proper widths of pavements and sidewalks on streets become an element in the designs to be handled. City street layouts and widths are big subjects covering a wide range from unimportant resident streets to pleasure boulevards and congested main streets. The subject is well covered by works by Robinson, Lewis, Blanchard, Agg, etc., and for special problems readers are referred to such works.

Connecting links in state highway systems through villages generally refer to main residential or business streets of villages or small cities. For these conditions central parking spaces are rarely desirable and the layout is the common one of roadway with side lawns or wide sidewalks from the curb to the street line.

For residential streets where occasional parking parallel to the curb prevails a width of paved street of 30 to 32 ft. between curbs is a satisfactory minimum on state route connecting links through villages where there are no street car tracks. Where double car tracks occur it is customary to increase the minimum to 36 ft. although this width does not give as great freedom of movement and a width of 45 ft. is advisable if the total width between street lines will permit. Sidewalks 5 ft. wide with a variable width of ornamental grass, tree or shrubbery parking with a minimum cross slope of $\frac{1}{4}$ to $\frac{3}{8}$ in. per foot serve very well. Excessive pavement widths are to be avoided on residential streets and wide side parking adds to the pleasing appearance of the street.

In business sections a minimum width of 50 ft. and preferably 60 ft. between curbs is desirable where there are no car tracks. Sidewalks from curb to building line should be at least 12 ft. if the total width of the street permits. For wide business streets it is rarely necessary to make the sidewalk more than 18 ft., the pavement taking up the balance of the space. Where street car tracks occur it is desirable to make the pavement as wide as possible without reducing the sidewalk width below the 12 ft. limit.

APPENDIX F

RECENT CONCRETE DATA

At various places in the text reference is made to the effect of time of mixing on strength; care in curing on strength and fineness modulus on strength. The following data briefed from publications of the Portland Cement Association gives the most recent data (1923) based on experiments at Lewis Institute under the direction of Prof. Duff Abrams.

Very often both contractor and inspector are somewhat skeptical as to the necessity for the more recent specification clauses based on rational care in aggregate sizing, time of mixing and care in curing. Even a casual inspection of the experimental results here recorded ought to convince any unbiased inspector of the necessity of care in these particulars.

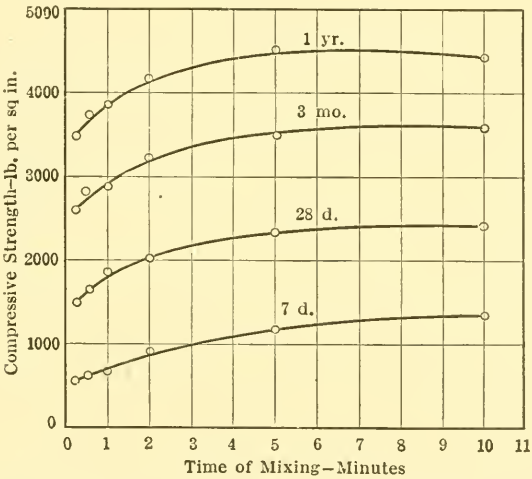

FIG. 1.—Relation between time of mixing and the compressive strength of concrete.

Proper Time of Mixing Increases Strength.—Effective mixing involves both time and number of revolutions. Many inspectors and contractors believe that the number of revolutions controls strength of mix and that by speeding up the mixer the time can be reduced without any detriment to the mix. The following diagrams show that the specification clauses involving both time and speed are essential clauses and that both must be complied with for the best results.

Proper Curing Increases Strength of Concrete.—Careful distinction should be made between the requirements of concrete for water during the mixing operation and in curing. A safe rule to follow is to use the smallest quantity of *mixing* water that will produce a sufficiently plastic mixture for the work in hand, and then to give the surface of the concrete as much *curing* water as possible after the concrete is placed.

Concrete hardens because of chemical reactions between portland cement and water. Down to an amount less than can be used in construction work, the smaller

the quantity of mixing water the stronger will be the concrete. Therefore, the quantity of mixing water should be reduced as far as possible. However, once the concrete is placed, and it has hardened, conditions change and ample curing water should be provided.

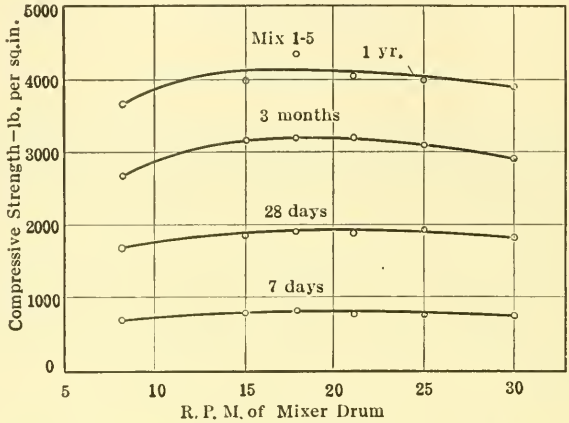

FIG. 2.—Relation between speed of mixer and the compressive strength of concrete.

The chemical reactions of the hardening of concrete are slow, and if sufficient moisture is not present they cannot be completed. The mixing water essential to proper hardening of freshly placed concrete is often lost by absorption or evaporation

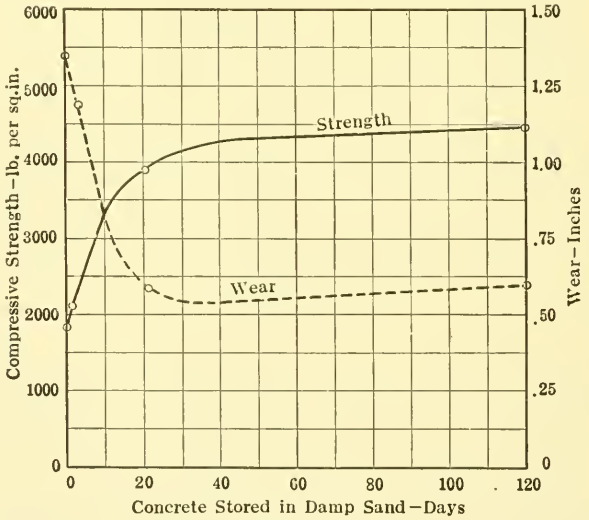

FIG. 3.—Keeping concrete damp the first ten days adds 75 per cent to its compressive strength. It reduces the amount of wear 40 per cent, or *vice versa*, increases the resistance to wear 65 per cent. Three weeks' protection adds still more strength and hardness.

even after the concrete has begun to harden. Under such conditions, concrete attains only part of its potential strength. Therefore, the water content of freshly placed concrete should be conserved. Keeping concrete damp during its early hardening

period, or, in other words, providing plenty of curing water, prevents evaporation of necessary moisture, and permits concrete to harden under favorable conditions.

Protect Concrete While Hardening.—Tests show that protection during the early hardening period greatly increases the strength and resistance to wear of concrete. Fig. 3 gives a summary of the results of these tests. All specimens were tested at the same age—4 months. One set was allowed to harden in air for the full 4 months; the second set was stored in damp sand for 3 days and in air for the remaining 117 days; the third set was stored in damp sand 21 days and in air the remaining 99 days; while the fourth set was stored in damp sand the full 120 days and was tested while still damp. Thus the increased strength and resistance to wear was caused solely by the better curing conditions provided.

Note that keeping concrete damp for the first 10 days increased its compressive strength 75 per cent, for 3 weeks 115 per cent, and for 4 months 145 per cent.

Note also that keeping concrete damp for the first 10 days decreased the amount of wear 40 per cent, and for 3 weeks 55 per cent. Keeping concrete damp for 4 months did not cause a further decrease in wear, but the specimens were tested damp. Had they been allowed to dry out for a few days before being tested, the amount of wear would probably have been less.

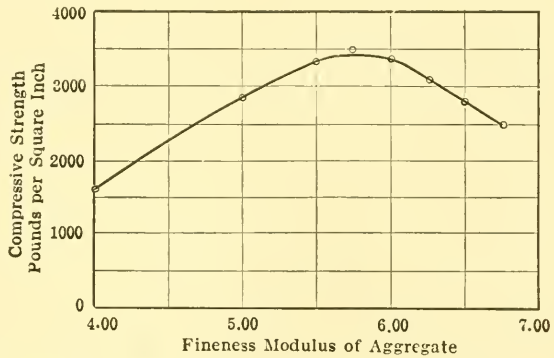

FIG. 4.—Relation between the grading of the aggregate and the strength of concrete.

Reversing the form of these wear results, 10 days protection increased the resistance to wear of concrete 65 per cent, and 3 weeks protection 120 per cent. Thus proper curing increases the resistance to wear of concrete almost in the same proportion as the compressive strength. Needless to say, resistance to wear is an important consideration in floors, pavements and platforms.

Careful Grading of Aggregate Increases Strength of Concrete.[1]—Portland cement, which forms only 15 to 25 per cent of the volume of concrete, is carefully tested to see that it meets exacting specifications. Aggregates, which form 75 to 85 per cent of the volume of concrete, should also be tested. Aggregates should be clean, free from coatings or organic impurities and structurally sound. Furthermore, proper size and grading of aggregates, or proper proportioning of fine and coarse aggregates, may double the strength of concrete, as shown in Fig. 4. Doubling the strength as the results of a few hours' study and a little closer supervision is surely worth while.

Grading of Aggregates Varies.—Any number of fine and coarse aggregates of widely different size and gradings may meet the usual specifications in those respects. If

[1] Quoted from Pamphlet of Portland Cement Association.

combined in arbitrary proportions, such as 1:2:4, some of them will make far better concrete than others. For best results a proportion should be determined for each case that will fit the particular aggregates to be used. A little study will quickly show which of two or more available aggregates is the better graded and will therefore make the best concrete. Consideration of these factors may permit the use of local materials, with a saving in freight. It may also result in securing high grade concrete at lower cost. Such studies can readily be made by any competent engineer or inspector, and at very small expense.

Assuming a given consistency, which should always be as stiff as the nature of the work permits, and a given mix (proportion of cement to total volume of mixed aggregate), the strength of the resulting concrete depends on the size and grading of the aggregate. In general, the larger and coarser the aggregate, the stronger will be the concrete. Coarse sand will produce stronger concrete than fine sand, while stone or pebbles in which the larger sizes predominate will produce stronger concrete than smaller stone or pebbles.

Fineness Modulus Shows Grading.—A simple index number, called the "fineness modulus," has been developed to indicate the size and grading of aggregates, and therefore their value for use in concrete. It can be applied to either fine or coarse aggregates, or to any combination of them. It shows at a glance which of two or more aggregates is the better graded. From it the proportions in which given fine and coarse aggregates should be combined are easily computed.

To determine the fineness modulus of an aggregate it is only necessary to make a simple sieve analysis. A set of U. S. standard square mesh sieves is used, each sieve having a clear opening double the width of the next smaller size. These sizes are 100, 50, 30, 16, 8 and 4 meshes per linear inch, and ⅜-in., ¾-in. and 1½-in. For larger aggregates 3-in. and 6-in. sieves may also be used. The percentage of the aggregate, either by weight or by volume, coarser than each sieve is measured. The sum of these percentages, divided by 100, is called the fineness modulus. A close approximation can be obtained by using only alternate sieve sizes, 50, 16, 4 and ¾, and estimating the percentages for the others. These four sieves make a convenient set for field use.

Table 2, on p. 609, gives the sieve analyses and fineness moduli of ten aggregates. The first is sand, the second, pebbles. The other eight aggregates were formed by combining these materials in various proportions. As the percentage of pebbles increases, the aggregate becomes coarser and the fineness modulus grows larger, thus reflecting the size and grading of the aggregate.

Good Grading Doubles the Strength.—The last column shows the compressive strength of concrete made from those eight aggregates in the proportions of one volume of cement to four volumes of total aggregate. These strengths are plotted in Fig. 4. Note that up to a certain point, the concrete increases in strength as the aggregate gets coarser. Beyond that point the aggregate is too coarse for the amount of cement used and the concrete decreases in strength. Note also that proper grading of aggregate may double the strength of the concrete. For other mixes the same principle holds true, although the greatest strength would be obtained with a different grading. The richer the mix, the coarser the aggregate and the larger the fineness modulus that will give the strongest concrete.

Aggregate No. 3, with a fineness modulus of 4.00, corresponds to a bank run gravel; it contains entirely too much fine material for best results. Aggregate No. 10, with a fineness modulus of 6.75, corresponds in grading to a crusher run stone; it contains too much coarse material. This shows the folly of using either bank run gravel or crusher run stone. Such material should always be screened and recombined in proper proportions.

TABLE 2.—SIEVE ANALYSIS AND FINENESS MODULUS OF AGGREGATE

Ref. No.	Sieve analysis. Per cent coarser than each sieve									Fineness modulus	Comp. strength of a 1:4 mix. lb. per sq. in.
	100	50	30	16	8	4	⅜	¾	1½		
1	99	93	63	40	20	0	Sand	..	..	3.15	
2	...	Pebbles		..	..	100	75	25	0	7.00	
3	99	93	68	55	39	23	17	6	0	4.00	1,630
4	99	95	79	70	59	49	37	12	0	5.00	2,910
5	100	95	84	77	70	62	46	16	0	5.50	3,370
6	100	97	86	79	73	68	51	21	0	5.75	3,540
7	100	98	90	85	79	74	56	18	0	6.00	3,390
8	100	98	91	89	85	81	61	20	0	6.25	3,150
9	100	99	94	93	90	87	65	22	0	6.50	2,790
10	100	100	98	96	94	93	70	24	0	6.75	2,540

Fineness Modulus is Simple.—The fineness modulus of any mixture of two or more aggregates, such as fine and coarse, is merely the weighted average of the fineness moduli of the separate materials. For example, if 32 per cent of sand No. 1 (*F. M.* = 3.15) is mixed with 68 per cent of pebbles No. 2 (*F. M.* = 7.00), the fineness modulus of the mixture is:

$$F.\ M. = \frac{32 \times 3,15 + 68 \times 7.00}{100} = 5.77$$

This agrees closely with the value given in the table (5.75) for aggregate No. 6, which was found by a sieve analysis.

Sieve analyses, which are easily made, will give the fineness moduli of any fine and coarse aggregates, while a simple calculation will show the fineness modulus of any mixture of them.

If the proper fineness modulus for the work in hand is known (see below), the proportions in which given fine and coarse aggregates must be combined to secure that fineness modulus can readily be computed.

Sieve analyses of aggregates may vary over a wide range, but as long as the sum of the percentages coarser than each sieve (fineness modulus) is the same, the aggregates may be expected to give uniform results in concrete. This relation is shown in Table 3, which gives the sieve analyses, fineness moduli and concrete strengths of 10 aggregates made up by artificial grading of the same sand and pebbles. Although the sieve analyses vary, the total, or fineness modulus, is the same in all cases. Note that all 10 aggregates made concrete of substantially the same strength, the mean variation from the average being only 6.2 per cent.

Thus the fineness modulus, which is an index of the size and grading, indicates the value of an aggregate for use in concrete. The reason is that, eliminating variations in the absorption of the aggregates, the fineness modulus reflects the quantity of mixing water necessary to obtain a given consistency. In general, consistency and mix being the same, the fineness modulus indicates the strength that can be expected in the concrete. Other conditions being the same, aggregates having the same fineness modulus will produce concrete of substantially the same strength.

TABLE 3.—STRENGTH OF CONCRETE FROM AGGREGATES OF UNIFORM FINENESS MODULUS

Mix 1:4 by volume. Relative consistency 1.10. Age at test 28 days. Specimens (6 by 12-in. cylinders) were stored in damp sand and tested damp

Ref. No.	Sieve analysis. Per cent coarser than each sieve									Fineness modulus	Comp. strength lb. per sq. in.
	100	50	30	16	8	4	⅜	¾	1½		
11	95	89	82	75	67	67	67	62	0	6.04	2,780
12	98	95	90	83	83	83	50	22	0	6.04	2,530
13	98	94	90	86	83	80	55	18	0	6.04	2,590
14	96	90	80	80	80	80	60	38	0	6.04	2,570
15	90	85	81	78	75	73	66	56	0	6.04	2,580
16	100	93	82	73	73	73	63	47	0	6.04	2,880
17	100	100	100	92	81	60	45	26	0	6.04	2,930
18	100	99	96	91	80	50	50	38	0	6.04	3,040
19	99	98	90	85	80	76	38	38	0	6.04	3,030
20	99	98	91	85	80	76	67	8	0	6.04	2,690
Average											3,760
Maximum value											3,040
Minimum value											2,530
Mean variation from average											6.2 per cent

Proportions Depend on Aggregates.—Applying this principle to actual construction, it means that if several fine and coarse aggregates are available, concrete of substantially the same strength can be made from any combination of fine and coarse material, provided that the materials are proportioned to have the same fineness

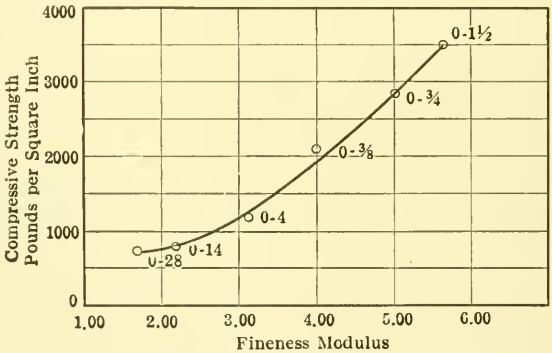

FIG. 5.—Relation between maximum size of aggregate, fineness modulus and strength of concrete.

modulus. For one set of materials the proper proportions may be 1: 2.3: 2.7, for another 1:1.6:3.4 and so on. To apply an arbitrary mixture, such as 1:2:3 to all aggregates, regardless of their grading, will not give uniform or satisfactory results.

The mixture should be determined after a study of the particular aggregates to be used. If the grading of the aggregate changes during the progress of the work it is an easy matter to change the mixture accordingly.

It is obvious that aggregates having a larger maximum size will have a larger fineness modulus. This is shown in Fig. 5. Note that as the maximum size increases, the fineness modulus increases, and also that the strength of concrete increases.

As stated before, larger fineness moduli can be used with rich mixes than with lean ones. Therefore, the best value of fineness modulus will depend on both the mix and the maximum size of the aggregate. Table 4, below, indicates the best value of the fineness modulus for the usual mixes and sizes of aggregates. The closer the aggregate comes to meeting these values the stronger will be the concrete.

These values for fineness modulus are based on sand and pebble aggregate for ordinary reinforced concrete. If crushed stone, slag or flat pebbles are used as coarse aggregate, or stone screenings as fine aggregate, reduce the values by 0.25. For mass work the values can be increased by 0.10 for ¾ in. aggregates, 0.20 for 1½ in. aggregate, and 0.30 for 3 in. aggregate. Fine aggregate used in concrete should not have a higher fineness modulus than that given for mortars of the same mix.

TABLE 4.—BEST VALUES FOR FINENESS MODULUS

Mix cement—aggregate	Size of aggregates						
	0–4	0–⅜ In.	0–¾ In.	0–1 In.[1]	0–1½ In.	0–2 In.[1]	0–3 In.
1:7	3.20	3.95	4.75	5.15	5.55	5.95	6.40
1:6	3.30	4.05	4.85	5.25	5.65	6.05	6.50
1:5	3.45	4.20	5.00	5.40	5.80	6.20	6.60
1:4	3.60	4.40	5.20	5.60	6.00	6.40	6.85
1:3	3.90	4.70	5.50	5.90	6.30	6.70	7.15
1:2	4.20	5.05	5.90	6.30	6.70	7.10	7.55
1:1	4.75	5.60	6.50	6.90	7.35	7.75	8.20

[1] Considered as "half size" sieves; not used in computing fineness modulus.

Shrinkage of Aggregates after Mixing.—Table 4 gives the true mix, *viz.* the proportion between the volume of cement (expressed as unity) and the volume of total aggregate after the fine and coarse have been combined. In the nominal mix, which is the one ordinarily used, the volumes of fine and coarse aggregates are given separately, *i.e.*, 1:2:4 or 1:1½:3. The nominal mix can readily be converted into the true mix. *Vice versa*, if the ratio between fine and coarse aggregate is known, the true mix can be quickly converted into the nominal mix. For the usual ratios of fine and coarse aggregate (fine aggregate being 20 to 70 per cent of the total) the volume of total aggregate after mixing will be about seven-eighths of the sum of the volumes of fine and coarse aggregate measured separately. For example, aggregate No. 6 in Table 2 contained 32 per cent sand. Four cubic feet of the total aggregate would require 4.57 cu. ft. (4.00 × ⅞) of fine and coarse aggregate measured separately. Of that 4.57 cu. ft., 32 per cent or 1.46 cu. ft. would be sand and 68 per cent or 3.11 cu. ft. would be pebbles. A 1:4 true mix would be obtained by using a 1:1.46:3.11 nominal

mix. Because of this shrinkage when fine and coarse aggregate are combined a 1:2:4 nominal mix does not correspond to a 1:6 true mix as sometimes assumed, but to about 1:5.2 true mix.

More accurate values for the shrinkage of mixed materials can be obtained by measuring the volume of mixed aggregate obtained by mixing fine and coarse aggregates in the proper proportions, or by calculation from the weights of unit volumes of fine, coarse and mixed aggregates. For most cases, however, the average shrinkage of one-eighth is sufficiently reliable.

Example 1.—Four fine aggregates and three coarse aggregates are available for a certain job. Which should be used? Their sieve analyses give the following data:

Aggregate	Per cent coarser than each sieve									Fineness modulus	Range in size, in.
	100	50	30	16	8	4	⅜	¾	1½		
Sand.....No. 1	100	90	70	55	35	20	0	0	0	3.70	0–⅜
Sand.....No. 2	100	85	65	40	20	0	0	0	0	3.10	0–4
Sand.....No. 3	95	75	60	30	0	0	0	0	0	2.60	0–8
Screenings.....No. 4	85	80	75	35	25	0	0	0	0	3.00	0–4
Stone.....No. 5	100	100	100	100	100	100	100	40	0	7.40	⅜–1½
Pebbles.....No. 6	100	100	100	100	100	100	70	30	0	7.00	4–1½
Pebbles.....No. 7	100	100	100	100	100	100	45	15	0	6.60	4–1

Because of better size and grading (larger fineness moduli) sand No. 1 and stone No. 5 are the best materials. Sand No. 2 and pebbles No. 6 are good materials, but sand No. 3 is quite fine and pebbles No. 7 are rather small. Screenings No. 4 are well graded, but an equally well graded sand would be preferable, because rounded particles find their way into place with less mixing water. That is the reason why a higher fineness modulus is permissible when sand is used than when screenings are used (see text preceding Table 4). Therefore the other materials would be better. Any of these materials will make good concrete, however, provided the fine and coarse materials are proportioned to secure a combined fineness modulus suitable to the mix and maximum size of the aggregate.

Example 2.—A 1:4 true mix and a 1½-in. maximum size of aggregate have been adopted. Sand No. 2 and pebbles No. 6 have been selected because their cost is less than that of the other materials. In what proportions should they be combined to get the best results? Or, in other words, what nominal mix should be used?

The proper value of the fineness modulus for these conditions is 6.00 (see Table 4). Then sand No. 2 and pebbles No. 6 must be combined in such proportions as to secure a fineness modulus of 6.00 for the total aggregate. Let P equal the percentage of sand and $100 - P$ the percentage of pebbles.

$$P \times 3.10 + (1.00 - P) \times 7.00 = 6.00$$
$$3.10P + 7.00 - 7.00P = 6.00$$
$$3.9P = 1.00$$
$$P = 0.26 \text{ or } 26 \text{ per cent}$$

Thus of the total volume of aggregate, 26 per cent should be sand and 74 per cent pebbles. The true mix being 1:4 the sum of the volumes of sand and pebbles for a

one bag batch measured separately will be 4.57 cu. ft. ($4 \times \frac{8}{7}$). Of this, 26 per cent or 1.19 cu. ft. will be sand and 74 per cent or 3.38 cu. ft. will be pebbles. The nominal mix will then be 1:1.2:3.4.

Example 3.—During the progress of the work it becomes necessary to substitute screenings No. 4 and stone No. 5. What change should be made in the nominal mix?

When screenings are used as fine aggregates or when crushed stone is used as coarse, the values for the total fineness modulus given in Table 4 should be reduced by 0.25. In this case screenings and crushed stone are both being used and the value of 6.00 for the fineness modulus used in Example 2 should therefore be reduced by 0.50, or to 5.50. Using the same notation as before:

$$P \times 3.00 + (1.00 - P) \times 7.40 = 5.50$$
$$3.0P + 7.4 - 7.4P = 5.50$$
$$4.4P = 1.9$$
$$P = 0.43 = 43 \text{ per cent}$$

Dividing the total volume of aggregate before mixing (4.57 cu. ft.), 43 per cent fine and 57 per cent coarse, the new proportions are found to be 1:2.0:2.6.

Summary.—The size and grading of the aggregate are important factors in the strength of concrete, because they affect the quantity of mixing water necessary to attain a given consistency. The fineness modulus is an index number that shows the size and grading. Therefore it reflects the quantity of mixing water that will be necessary and indicates the strength to be expected in the concrete under given conditions. It can be quickly calculated from a simple sieve analysis. The fineness modulus of any combination of fine and coarse aggregates is the weighted average of their separate fineness moduli. Study of the fineness modulus will show the proportions in which given fine and coarse aggregates should be combined for best results. Proper proportioning of fine and coarse aggregates may double the strength of concrete.

INCREASED STRENGTH FROM RICHER MIXES

Tests clearly bring out the increase in strength resulting from the use of richer mixes. Typical results are given in the following table. The same aggregate, with a fineness modulus of 5.75 and graded up to 1½ inches in size, was used in all tests. The cement was a mixture of equal parts of four brands purchased on the Chicago market. The relative consistency of all specimens was the same, 1.10, with a slump of 3 to 4 inches. This consistency is suitable for most construction work. All tests were made at the age of 28 days. Thus the increase in strength was due solely to increases in the quantity of cement.

Ordinary concrete mixes (1:3½:7 to 1:1½:2) contain from 3 to 8 sacks of cement per cubic yard of concrete. Note that within this range the strength of concrete increases in direct proportion to the quantity of cement. Each additional sack of cement per cubic yard adds about 500 pounds per square inch to the strength of concrete.

EFFECT OF QUANTITY OF CEMENT ON THE STRENGTH OF CONCRETE

True mix[1]	Approximate nominal mix[1]	Sacks of cement per cubic yard of concrete	Compressive strength, lbs. per square inch
Neat	.....	29.7[2]	6,630
1:⅓	.....	23.0	5,720
1:1	1: ⅜: ¾	15.7	5,070
1:2	1: ¾: 1½	10.5	4,070
1:3	1:1½: 2	7.9	3,570
1:4	1:1½: 3	6.3	2,760
1:5	1:2 : 3½	5.2	2,090
1:7	1:3 : 5	3.9	1,400
1:9	1:3½: 7	3.1	1,030
1:15	1:6 :12	1.8	440

[1] The true mix is the ratio between the volume of cement, expressed as unity, and the volume of total aggregate after the fine and coarse have been combined. In the nominal mix, which is the one ordinarily used, the volumes of fine and coarse aggregate are expressed separately. The nominal mix can readily be converted into the true mix because for the usual proportions of fine and coarse aggregate (fine aggregate 20 to 70 per cent of the total) the volume of combined aggregate after mixing is about seven-eighths of the sum of the volumes of fine and coarse aggregate measured separately. Because of this shrinkage a 1:3:5 nominal mix does not give a 1:8 true mix as sometimes assumed, but about a 1:7 true mix.

[2] The volume of concrete obtained from neat cement depends on the quantity of mixing water used. For water-cement ratios beween 0.3 and 0.6, the volume of concrete obtained from one sack (one cubic foot) of dry cement equals 0.5 of a cubic foot plus the amount of water used. In the example given here the water-cement ration was 0.4 and the shrinkage was therefore about 10 per cent.

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